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ECONOMIC EVALUATION OF MINERAL DEPOSIT: A BOTTOM-UP APPROACH

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ABSTRACT

Proper economic evaluation of a mineral deposit is critical to effective investment decision-making in a mineral project. However, this often requires detailed mine production scheduling to produce a schedule that reflects the actual cash flow when the project comes on stream. Because of the dexterity required for this task, many mine planners and explorationist attempt to use statistical formulas that approximate the mine scheduling and value of the project. The mathematical model developed for production scheduling often produces a constant production rate schedule over an approximate life span of the project. In this paper, we have attempted to apply a bottom-up approach that begins with geometrical modelling and equipment deployment pattern to define the number of equipment required for each sequence of operation based on available workfront in the development of each bench. Then, based on the number of equipment and the production rate at each sequence of operations, a production schedule is developed. This production schedule therefore will reflect annual cash flow since it is based on the sequence of operation. Application of this method on the west pit of Itakpe mine shows a considerable net present value and internal rate of return of the deposit compared with the evaluation made using statistical models. The NPV of the west pit was found to be USD621 million as against USD122.41 million using Nwosu's formula and USD123.85 million Taylor's formula. The above value of NPV using the proposed method shows the maximum expected NPV of the mineral project-based technical restrictions. An understanding of this value can guide the mineral property owner in decision-making.

Keywords: bottom-up approach, workfronts, net present value, internal rate of return.

INTRODUCTION

Proper economic evaluation of a mineral deposit is sine qua non to proper investment decision-making in the mineral industry. Hence various authors like O'hara (1992) developed cost estimation methods that easily provide input data for mineral evaluation. Gentry (1984) wrote a treatise on the subject matter of mineral property evaluation and investment analysis. Adebimpe and Akande (2011) applied the Russian mineral evaluation approach to evaluate the economic worth and payback period of the deposit.

To properly evaluate a deposit three steps must be followed (Nwosu and Onwualu, 2019).

1. Production scheduling
2. Cashflow development
3. Investment analysis proper

It is only when we get it right in the above three steps that mineral property evaluation will be able to guide the investor to make a proper investment decision.

Ideally, production scheduling should be determined from the mine calendar which shows how many tons of ore and waste should be mined at a specific period of mine life. However, this requires much detail in pit planning, which often is not within the expertise of an exploration geologist. Even in this detailed approach, the equipment deployment pattern and effect on production rate are hardly considered. To make mineral evaluation less cumbersome, several mine planners have developed some statistical models which give some close results without involving much technical estimation. Hence, Taylor (1986) proposed a statistical method which was presented as a rule-of-thumb model for production rate estimation. Nwosu (1994) developed a statistical model using the production schedule of 100 iron ore mines in Russia. Nwosu and Onwualu (2019) applied this model for production scheduling and economic evaluation of the Ajabanoko open-pit mine. Both models developed by Taylor and Nwosu respectively were statistical and relied on the constant production rate of the mine throughout mine life. In practice, the production rate increased gradually as the mine deepened and more mine work fronts and faces were created. The statistical methods started from the up i.e., estimating the production rates and life of the mine without considering the deepening rates that could be achieved, the workfronts that could be created, how many equipment could be deployed on each bench and the production capacities of these equipment. The bottom-up approach started by considering the deepening rate that can be achieved, the length of workfront that can be created, how much equipment can be deployed on each bench and the production capacities of this equipment. Hence, the production schedule established by the bottom-up approach creates a more realistic cash flow than the statistical approach.

METHODOLOGY

The bottom-up method of mineral evaluation proceeds as follows.

1. Mine sequencing and geometrical modelling were carried out to establish the total work front of the mine on each bench.
2. The total number of equipment required to operate the mine at each sequence of mine operation was estimated using the total workfront for that sequence and the length of work front
3. Equipment availability analysis was done and the block length for each sequence was adjusted.
4. The total material mined from each sequence of mine operation was measured to establish the stripping ratio for each sequence. This stripping ratio is now used to separate the total equipment used for ore exploitation and those used for waste removal.
5. The total ore produced in each sequence was established using the total number of equipment estimated for ore production.
6. The deepening rate for each sequence and the time spent on the extraction of each sequence were established using the following formula.

   Deepening rate of open pit mine

$$h_r = \frac{nQ}{hLB\,(cot\varphi + cot\beta)} \quad \text{(Nwosu 2022)(1)}$$

Where;

h_r = deepening rate of open-pit for each sequence

n = number of equipment required for each pushback of operation or sequence.

Q = extraction equipment throughput

h = bench height

L = block length in each sequence

φ = operating angle

B = Width of bench working room

β = pit deepening angle

Using pit deepening rate and bench height, the extraction time for each pushback can be established using the following relationship.

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$$T_{ex} = \frac{h}{h_r} \quad (2)$$

Where;

T_{ex}=extraction time for each sequence

The production in each sequence was divided by the time of extraction in that sequence to form the production rate of that sequence.

The time for extraction of each sequence was now summed up to establish the life span of the pit. Then the production rate in all the sequences was transformed into annual production rates.

1. A graph of annual production rate vs time is plotted
2. A cash flow table is now developed to prepare the stage for mine investment analysis.
3. Mine investment analysis is carried out in the following order:
    i) The cash out flow and net profits are discounted to the present day using the compound interest formula.

$$P = \frac{F_t}{(1+r)^t} \quad \text{(Pandey 2006)} \quad (3)$$

Where:

P = Present value of future cashflows

F_t = Cashflow at time t

r = discount rate

    ii) Capital cost = T_c is calculated using the following formula

$$T_c = \frac{T_o}{0.75} \quad \text{(Nwosu and Onwualu 2019)} \quad (4)$$

Where:

T_o = Sum of present value of cash outflow throughout the life of the project

    iii) Net present value NPV is established by

$$\text{NPV} = \sum_{i=1}^{t} N_p - T_c \quad (5)$$

Where: N_p = Sum of present value of annual net profits

    iv) Internal rate of return (IRR) is then established using the trial-and-error method.

RESULTS AND DISCUSSION

As stated in the methodology, the bottom-up approach starts with geometrical modelling of minefields to generate mine work fronts. This has been done using cross-sections 36 + 50 of the west pits of the Itakpe deposit. The bench height used is 10m while the bench working room is 50m. Fig.1 is the geometrical model of extraction operations. Using the geometrical models of extraction table 2 has been developed based on the approach stated under methodology. The table shows how much extraction equipment is required for each extraction sequence (Nwosu 2022). Using this table, we now proceed to prepare a production scheduling graph and table.

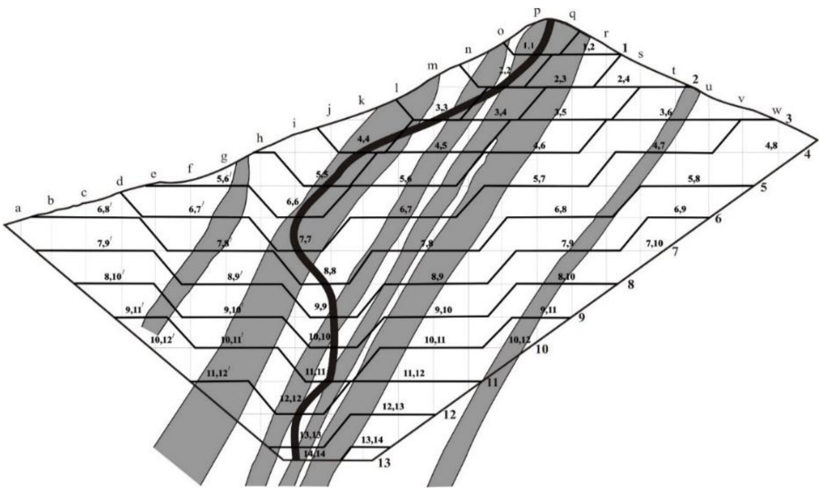

Fig 1: Geometrical modelling for establishment of workfronts and equipment required. (Nwosu 2022)

Table 1: Computation of pit parameters and equipment deployment (Nwosu 2022)

Bench No	Sequence	Length of Workfront	No. of Equipment needed	No. of Equipment Available	No. of Equipment Unavailable and need to be Replaced	Additional No. of Equipment	Block length after adjustment	Deepening Rate	Time of bench extraction	Cumulative time
1	1,1	1000	3	3	Nil	Nil	333	4.5	2.22	2.22
2	2,2	2000	5	5	Nil	2	400	6.3	1.58	3.8
3	3,3	2000	5	5	Nil	Nil	400	6.3	1.58	5.38
4	4,4	3000	8	8	Nil	3	375	5.4	1.85	7.23
5	5,5	3000	8	8	Nil	Nil	375	7.1	1.4	8.63
6	6,6	5000	13	8	Nil	5	385	11.3	0.85	9.48
7	7,7	5000	13	13	Nil	Nil	385	13.0	0.77	10.25
8	8,8	7000	18	13	+3	5	389	15.2	0.66	10.91
9	9,9	6000	15	18	Nil	Nil	333	18.85	0.53	11.74
10	10,10	5000	13	18	Nil	Nil	278	20.7	0.43	12.22
11	11,11	5000	13	16	-2	Nil	313	16.36	0.61	12.83
12	12,12	5000	13	16	Nil	Nil	313	19.72	0.51	13.34
13	13,13	3000	8	16	Nil	Nil	188	27.38	0.37	13.7
14	14,14	2000	5	11	Nil	Nil	180	19.68	0.50	14.20

Table 2: Production scheduling of west pit of Itakpe mine

Yr of Prod	No of Equipment Required	Stripping Ratio T/T	Production Rate in ore	Adjusted Production Rate in ore	Waste	Concentrate
1	3	0.07	4.2	4.2	0.29	1.47
2	5	0.29	5.8	5.8	1.68	2.03
3	5	0.92	3.9	6.4	5.90	2.24
4	8	1.0	6.0	8.0	8.00	2.8
5	8	1.06	5.82	8.0	8.48	2.8
6	13	1.19	5.5	8.0	9.52	2.8
7	13	1.4	8.1	8.0	11.20	2.8
8	18	1.93	9.2	9.2	17.76	3.22
9	15	1.36	9.5	10	13.6	3.5
10	13	1.17	9.0	10	11.70	3.5
11	13	0.96	10	10	9.60	3.5
12	13	0.79	11	10	7.9	3.5
13	8	0.74	6.9	6.9	7.4	2.42
14	5	0.94	3.86	3.86	6.45	1.35

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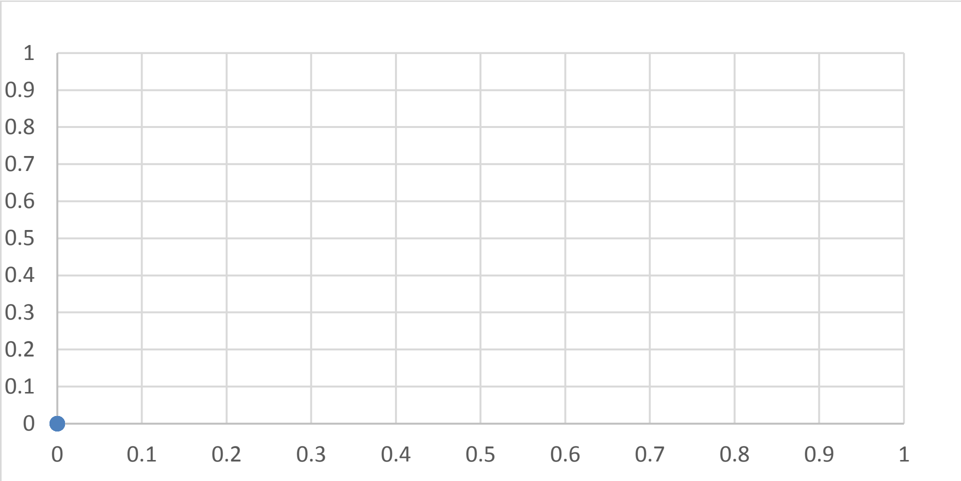

Fig 2: Production scheduling of west-pit of Itakpe mine

The table below shows the techno-economic data for cash flow development

Table 3: Techno-economic data for cash flow development

Unit cost of mining	Unit cost of waste removal	Concentrate yield per ton of ore	Price per ton of concentrate	Cost of processing per ton of ore	Cost of capital
3USD	2USD	0.35	100USD	3.6USD	10%

Table 4: Cash flow development of west pit of Itakpe mine

CASH FLOW TABLE

Year of Production	Annual mining cost	Annual processing cost	Annual waste removal	Cash outflow	Cash inflow	Gross profit	Royalty	Profit before tax	Tax	Net profit
1	12.6	14.7	0.58	27.88	147	119.12	47.65	71.47	7.15	64.32
2	17.4	20.3	2.36	40.6	203	162.4	64.96	97.44	9.74	87.7
3	19.2	22.4	11.8	53.4	224	170.6	68.24	102.36	10.24	92.12
4	24	28.0	16.00	68.00	280	212	84.8	127.2	12.72	114.48
5	24	28.0	16.96	68.96	280	211.04	84.4	126.6	12.66	113.94
6	24	28.0	19.04	71.04	280	209.00	83.6	125.4	12.54	112.86
7	24	28.0	22.4	74.4	280	205.60	82.24	123.36	12.34	111.02
8	27.6	32.2	35.52	95.32	322	226.70	90.68	136.02	13.60	122.42
9	30	35.0	27.2	92.2	350	257.80	103.12	154.68	15.47	139.21
10	30	35.0	23.4	88.4	350	261.60	104.64	156.96	15.70	141.01
11	30	35.0	19.2	84.2	350	265.8	106.32	159.48	15.95	143.53
12	30	35.0	15.8	80.8	350	269.2	107.68	161.52	16.15	145.37
13	20.7	24.15	14.8	59.65	242	182.35	83.00	109.35	10.94	98.41
14	11.6	3.51	12.9	38.01	135	97.0	38.8	58.2	5.82	52.38

Net Present Value Estimation (NPV)

As shown in formula (6), NPV involves the estimation of capital outlay on the project and the sum of discounted net profit.

As shown by Nwosu and Onwualu, the capital cost of a project can be estimated as follows;

The capital outlay on a project T_c

Tc = 0.25T

$T = \frac{T_o}{0.75} = \frac{474}{0.75} = 632$ million

To = sum of discounted cash outflow (table 5)

Therefore, capital outlay

$T_c = 0.25 \times 632 =$ USD158 million

The sum of discounted annual profit at a 10% discount rate has been estimated in Table 5. Consequently

$NPV = \sum_{i=1}^{t} N_p - T_c$

$= 779.32 - 158$

= 621.32 million USD

Table 5: Showing discounted cash outflow and discounted net profit.

Year of production	Discounted cash outflow at 10% in million US$	Discounted net profit at 10% in million US$
1	25.35	58.47
2	33.55	72.5
3	40.12	69.22
4	46.45	78.2
5	42.83	70.8
6	40.1	63.7
7	38.15	56.9
8	44.54	57.21
9	39.1	59.0
10	34.1	54.37
11	29.51	50.31
12	25.75	46.33
13	17.29	28.53
14	10	13.78
Sum	**474.04**	**779.32**

Estimation of Internal Rate of Return (IRR)

Internal rate of return was estimated by the trial-and-error method i.e., the annual net profits were discounted with increasing discount rates until the NPV is zero or negative. Then a graph of NPV

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versus discount rates is plotted to establish the discount rate when NPV is zero. To achieve this, the net profits have been discounted by 13%, 15% and 16% and the sum of discounted net profits at the various discount rates are shown in table 6. NPVs have been estimated at various interest rates and displayed in Table (7). In Fig (3) a plot of NPVs versus discount rates shows the IRR to be 15.6%.

Table 6: Showing discounted net profit at various discount rates

Year of production	Discounted net profit at 13% in million US$	Discounted net profit at 15% in million US$	Discounted net profit at 16% in million US$
1	49.48	42.88	40.2
2	51.9	39	34.20
3	41.9	27.3	22.5
4	40.02	22.45	17.5
5	30.7	15.0	10.86
6	23.37	9.9	6.7
7	17.68	6.5	4.1
8	15.0	4.8	2.82
9	13.13	3.6	2.0
10	10.22	2.4	1.23
11	8	1.67	0.8
12	6.3	1.12	0.5
13	3.3	0.5	0.21
14	1.3	0.2	0.1
Sum	**270.59**	**177.32**	**146**

NPV at 13%

= 270.59 – 158

= 112.6 million USD

NPV at 15%

= 177.32 – 158

= 19 million USD

NPV at 16%

= 146 – 158

= -12 million USD

Table7: Showing NPVs versus discount rates

NPV (million USD)	621.32	112.6	19	-12
Discount rate (%)	10	13	15	16

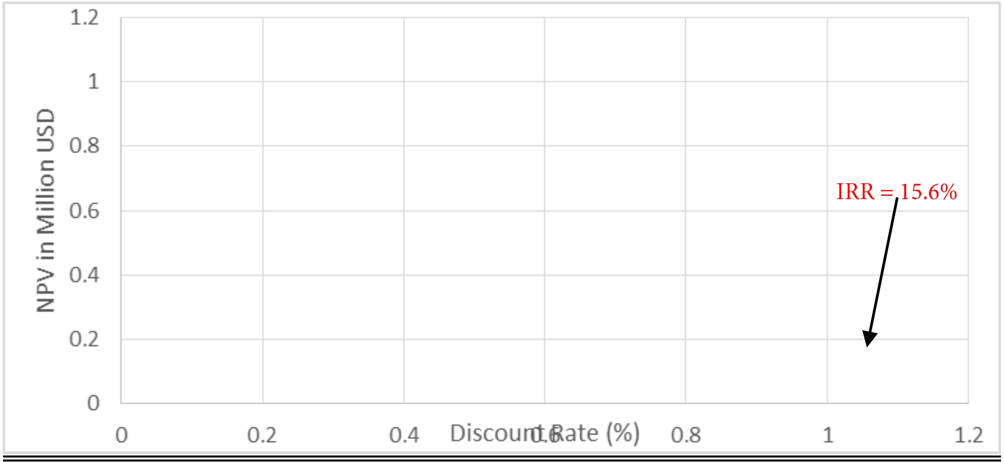

Fig 3: NPV vs discount rate

Using Nwosu's Method (Nwosu and Onwualu 2019)

Production Rate

A = $\frac{25B}{420+B} = \frac{2,700}{528}$ = 5.11mt

Lifespan = $\frac{Reserve}{Production\ Rate} = \frac{108}{5.11}$ = 21years

The Production rate and cashflow development table are calculated and presented in table (8)

Capital outlay

T_c = 0.25T

T = $\frac{92.07}{075}$ = 122.76 million USD

T_c = 0.25 x 122.76

= 30.69 million USD

NPV Estimation

NPV = $\sum_{i=1}^{t} N_p - T_c$

= 153.1 – 30.69

= <u>122.41 million USD</u>

Table 8: Cash flow development of west-pit of Itakpe mine

yrs of prod	prod rate	annual prod of conc	annual waste removal	Annual mining cost	annual cost of processing	annual cost of waste removal	Cash outflow	Cash inflow	Gross Profit	Royalty	Profit before tax	taxation	Net profit	Discounted cash outflow	Discounted net profit
1	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
2	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
3	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
4	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
5	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
6	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
7	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
8	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290

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9	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
10	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
11	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
12	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
13	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
14	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
15	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
16	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
17	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
18	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
19	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
20	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
21	5.11	1.79	5.06	15.33	18.396	10.12	43.84	178.85	135.01	54.00	81.00	8.100	72.903	4.384	7.290
														92.072	153.097

Using Taylor's Formula (Taylor 1986)

Production rate, A

$A = 4.88T^{0.75}$

Where, T is reserve = 108,000,000

A = 4.88 x 108,000,000

= 5.17mt

Lifespan = $\frac{Reserve}{Production\ Rate} = \frac{108}{5.17}$ = 21years

The Production rate and cashflow development table are calculated and presented in table (9)

Table 9: Cash flow development of west-pit o Itakpe mine

yrs of prod	prod rate	annual prod of conc	annual waste removal	Annual mining cost	annual cost of processing	annual cost of waste removal	Cash outflow	Cash inflow	Gross Profit	Royalty	Profit before tax	taxation	Net profit	Discounted cash outflow	Discounted net profit
1	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
2	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
3	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
4	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
5	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
6	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
7	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
8	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
9	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
10	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
11	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
12	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
13	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
14	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
15	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
16	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
17	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
18	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
19	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
20	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
21	5.17	1.81	5.12	15.51	18.612	10.24	44.36	180.95	136.59	54.64	81.95	8.195	73.759	4.436	7.376
													SUM	**93.153**	**154.895**

Capital outlay (Nwosu and Onwualu 2019)

$T_c = 0.25T$

$T = \frac{93.153}{075} = 124.2$ million USD

$T_c = 0.25 \times 124.2$

= 31.05 million USD

NPV Estimation

$$NPV = \sum_{i=1}^{t} N_p - T_c$$

= 154.90 – 31.05

= 123.85million US

CONCLUSION

The bottom-up approach has shown very high NPVs and at the same time has utilized available workfront and equipment deployment patterns in estimating production scheduling for economic evaluation of mineral deposits. The cash flow table is more realistic than that of the statistical approach since it follows equipment deployment patterns and workfront development in the pit. While this approach is less cumbersome than production scheduling established through detailed mine design, it offers the same depth of solution that detailed mine design offers.

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