IOSR Journal of Engineering (IOSRJEN) www.iosrjen.org
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 12, Issue 4, April. 2022, || Series -I || PP 01-07

Mine Sequencing and Equipment Deployment Planning For Open-Pit Mining Of Steeply Dipping Ore Deposit

***Nwosu J.I**

Department of Geology, Faculty of Science, University of Port Harcourt, Nigeria
Received 28 March 2022; Accepted 10 April 2022

ABSTRACT

Proper mining sequence is critical to viable development of an open-pit mine. It determines the volume of cash and the time the cash will begin to flow into the project. Improper mine sequencing can create a scenario of spending heavily now and posting the cash inflow to future time. In this paper, optimum mine sequencing criterion has been suggested. The paper suggests that maximum profit per ton of total materials exploited should be used to determine the optimum position of siting the development box-cut on each bench. The collective positions of these box-cut determine the sequence of mining operation. Based on the positions of the box-cuts defined by the criterion above, geometrical modelling of the pit was done on a cross-section 36 + 50 of National Iron Ore Mining Company Ltd, Itakpe. The geometrical modelling reveals the length of the workfront involved in each pushback and number of equipment required for its extraction based on block length of 400m. The deepening rate, extraction time for each sequence and cumulative extraction time were estimated for equipment deployment analysis. The equipment deployment analysis shows the number of equipment required to be added to the already existing fleet at each period of mine life and how many equipment should leave the mine due to old age. Using the equipment deployment analysis, block length can be adjusted (increased or decreased) in order to balance the life of equipment fleet with the overall life of the pit. Consequently, the suggested criterion has produced an optimum mining sequence locus and pushback pattern that yielded an extraction equipment requirement of 18 excavators for the initial fleet and 3 replacement excavators. Mine life was estimated to be 14yrs for the west pit portion of Itakpe open-pit mine.

1. INTRODUCTION

Mining sequence in an open-pit mining can be defined as the locus of movement of all box-cuts showing the pattern of the pushbacks in an open-pit mine. In order words, the mining sequence shows the way or order in which the pushbacks are arranged in an open-pit mine.

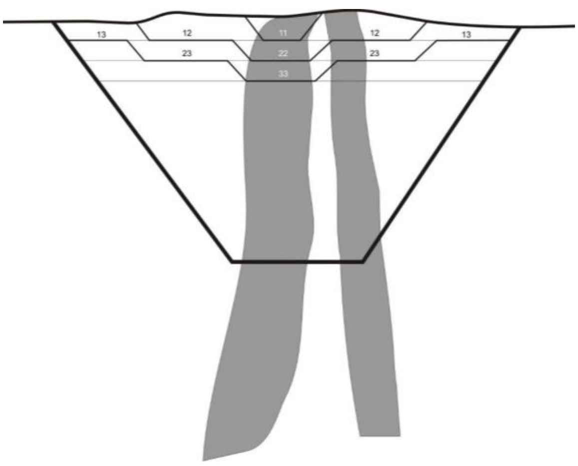

Fig 1: Illustration of pushback system

Consider figure 1, a cross section of ore bodies consisting of three benches. The first box-cut has been sited on position marked 1,1. This box-cut defines the first stage of mining on bench 1. In order to site the second box-cut on bench No. 2, the box-cut on bench No. 1 has to be expanded on both sides to create space for the construction of box-cut No. 2. The mining work on the expansion of box-cut on bench No. 1 and the creation of box-cut on bench No. 2 form the second stage of mining operation (2,2 1,2 1,2').

Where;

2,2 = second stage of mining operation with mining work taking place on bench 2

1,2 = Second stage of mining operation with mining work taking place on the right flank of bench 1.

1,2' = Second stage of mining operation with mining work taking place on the left flank of bench 1.

Similarly, 1,3; 2,3; 3,3 1,3'; 2,3' represents the third stage or pushback.

The positions of these box-cuts on the benches define the direction of mining work (mining sequence) in the pit.

Albor and Dimitrakopoulos (2010) define pushback as aggregation of mining blocks which are used to guide the sequence of extraction of an ore body from the point where the mining operation begins to where it stops. This definition in our own opinion more reflects the practical reality than the definition by Ramazan et'al (1996) that a pushback is part of a deposit that can be exploited between 1 to 10 years. Daniel et'al (2018) have shown that selection of proper positions of pushbacks is a *sine quo non* for the maximization of the net present value of a deposit. The position of the box-cut define the starting point of a pushback

Mine sequencing affects the operational parameters of a pit. The position of development box-cuts on each bench affects the number of extraction blocks that can be created, depending on the geometry of the deposit. On the other hand, the number of extraction blocks and their lengths decides the number of extraction equipment that can be deployed for each pushback or stage of operation. Therefore, mine sequencing for a deposit must be followed by geometrical modelling of mine field to define the blocks and workfront, the number of equipment needed for mine operation at each sequence, mine annual deepening rate and life span of the mine. Arayo et'al (2020) also emphasized on how proper selection of pushback width can affect equipment productivity.

Mine Sequencing

The position of the box-cut on each bench is not chosen at random, but must be chosen with definite objective. Several researchers (mine planners) have attempted to define the criterion on which the choice of the position of the box-cut must be based. To our knowledge, one of the earliest scientifically backed work on this was Arsentieve (1970). He proposed that the box-cut on each bench must be sited in such a way that the initial extraction work will be done with least possible stripping ratio. He developed the first graphical method of achieving this by constructing the isolines of equal ore extraction. By moving a model of the push-backs on the various positions on the isolines and calculating the volume of waste, he defined which position on the isoline would provide the least stripping ratio. Xiaowei et'al (2021) applied dynamic programming to achieve the least stripping ratio criterion. Furthermore, in an attempt to provide the mining sequence in the case of exploitation of complex ore deposits, Arsentieve and Halodnikov (1990) applied the criterion of minimum cost of mining and used similar graphical construction to define the position of siting the box-cuts.

Whereas the above criteria have their own merits, it is our opinion that the drive to develop a mineral deposit by an investor is profit maximization. Therefore, in this work, we propose that the box-cut must be sited as to maximize investor's profit per ton of total material (ore + waste) for each pushback.

The methodology of achieving the above criterion of maximum profit per ton of total material involved in each pushback starts by dividing the cross-section of the deposit into benches of 10m each. Furthermore, vertical lines spaced at 10m from each other are drawn. The points of intersection of the platforms of the benches with the vertical lines form the trial positions for optimal siting of the box-cuts i.e the position of maximum profit (fig 2). Thereafter, a pushback is drawn from each of the intersections starting with the uppermost (bench No.1). For each pushback, unit cost of mining, waste removal and processing as well as the yield and value per ton ore are used to ascertain the possible profit that can be generated by siting the box-cut at each intersection point. Then profit per ton of total material is calculated using the tonnage of ore and waste in the pushback created by siting the box-cut at that point. This is done for every trial position (point of intersection of the vertical lines with bench platform) making sure that the areas already encroached by previous pushbacks are excluded from further analysis. The result is a field of points with associated profit per ton of total material (fig 3). When the points with maximum profit per ton of total material for each of the benches are joined, we get a locus of points showing the position of box-cut on each bench that can generate the maximum profit by siting the box-cut on each of them (fig 4).

The same technique is applied for each cross-section to define the maximum profit locus of movement of box-cut. To achieve the objective in three dimension, the ultimate pit limit is drawn with access road inscribed on them. Thereafter, the level plans are extracted from them. For each level plan the position of the box-cut with maximum profit is located using the cross-sections. When the cross-section might have been sited on each bench, then the points are joined showing the horizontal movement of the box-cut that generates the maximum profit per ton of material. This is done for all level plans, consequently providing the three-dimensional solution.

Equipment Deployment Analysis

Just establishing the optimum mining sequence is not enough for ensuring a project overall success and profitability. There must be geometrical modelling of pit extraction system to establish the length of workfront generated by this sequence and the number of extraction equipment required to execute the mining operation at each stage or mining sequence. Furthermore, the required equipment fleet at each stage of the exploitation, and those that need to leave the production system due to old age and replaced by new ones are analysed.

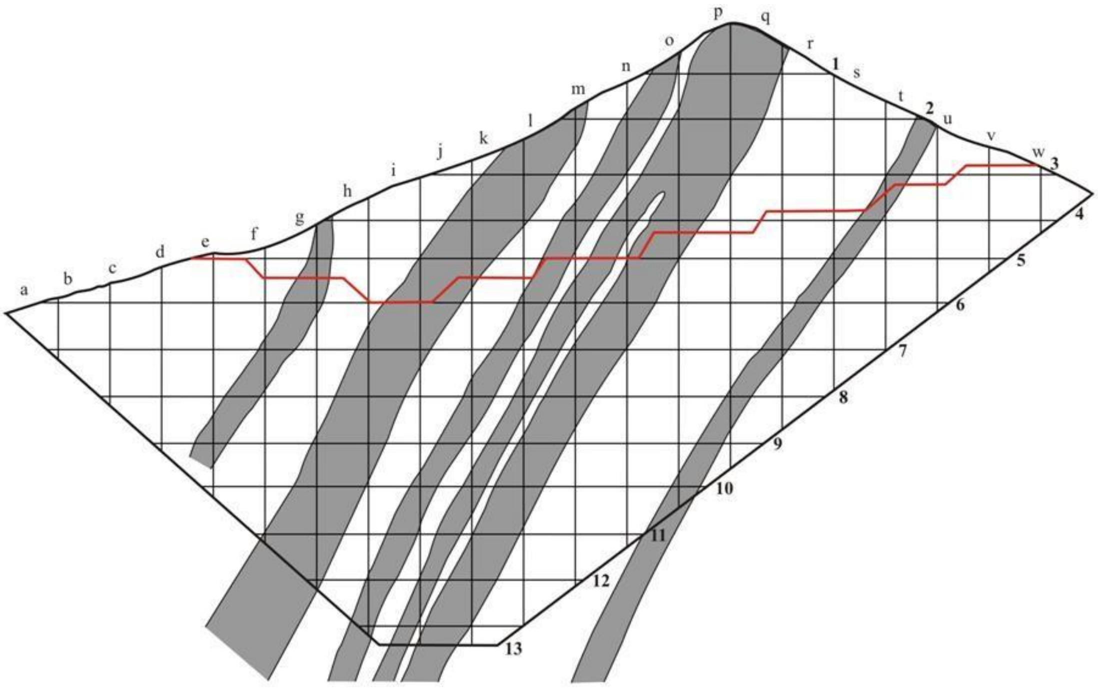

Fig 2: Point of interception of vertical lines with bench platforms for seeking the optimum position of siting the box-cuts.

1														55.36	61.24	53						
2												26.16	34.12	39.24	26.76	26.16	23.2	19.6	12			
3										23.2	24.2	26.04	23.04	20.8	20	18.4	16.4	14.8	14.4	11.2	6	
4							16	18	17.88	19.68	17.84	17.6	16.4	15.6	14.4	15.2	10	9.4	8.4	5.6	5	4.8
5				8.4	9.72	10.2	10.28	11.72	12.4	11	10.68	10.24	9.76	9.28	9.2	8.8	7.6	6.72	6.28	5	4.32	
6	6.28	7.88	8.04	8.68	9.48	9.84	10.12	10.4	9.2	8	7.8	7.64	7.56	7.4	6.64	5.6	4.84	4.4	3.6	4.8		
7	6.84	7	7.2	7.52	7.6	7.92	8.08	9.48	7.92	7.48	7.56	7.08	6.96	6.6	6.24	5.48	5.12	4.32				
8		4.92	5.84	7	7.56	7.56	7.72	8.4	9.2	7.8	7.6	7.52	7.24	6.52	6.28	5.72	5					
9			8	9.6	9.92	10.12	11.2	12	13	11.6	11.36	11.28	10.8	10.64	10.52	10.28						
10				10.08	10.8	10.4	11.6	13.28	14.6	12.48	12	11.84	11.4	11.6								
11					10.08	11.92	12.8	15.24	16.4	14	13.2	12.36	11.8									
12						18.68	20.08	20.8	20	19.2	18.64	11.24										
13								27.67	26.28	24.8												

Fig 3: Profit field showing the profit to be made by siting the box-cut at each trial point (intersection)

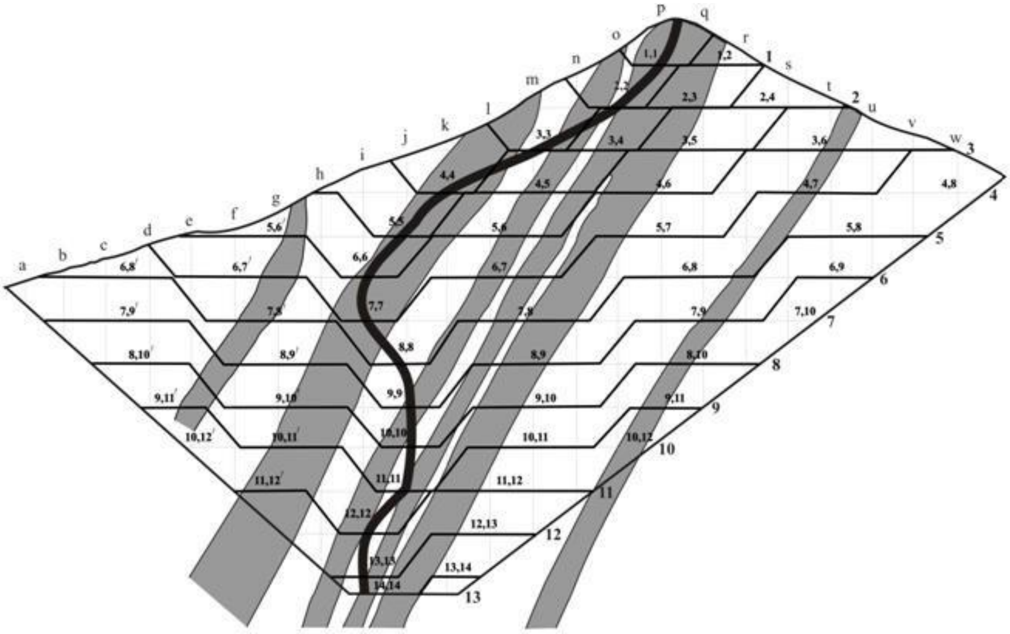

Fig 4: The mining sequence showing the locus of movement of the box-cut from bench to bench

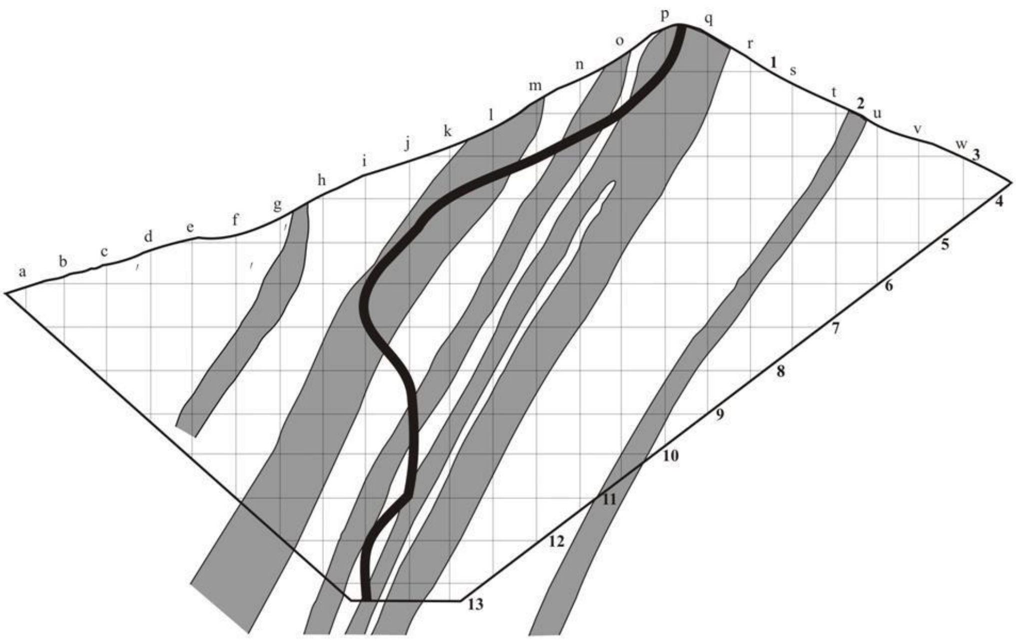

Fig 5: The geometrical modelling of open pit mine (Cross section 50+36) of National Iron Ore Mining Company Itakpe, Nigeria.

Geometrical modelling of open-pit mine field (fig 5) starts by creating the box-cuts and blocks on each bench. At each level, the box-cut is created on the position defined above using the maximum profit per ton of material. From the position of this box-cut on each bench, workfronts and blocks are created by generating the pushbacks. Then, using the optimum block length of 400m per excavator (Giproruda) for automobile haulage as a base, the length of the block can be adjusted as the need arises. The number of equipment required for the entire workfronts of each pushback is established by simple division of the length of workfront by block length. From the diagram above (fig 5), the workfronts on bench No.1 is 1000m which is the length of the ore deposit along the strike. Hence, 3 equipment are needed to excavate the 1000m length of workfront using a block length of 333m each. On bench No.2 the optimum position of the box-cut is designated (2,2) which is the starting point of the second pushback. In the same pushback excavation will be carried out on bench No.1 right of the box-cut i.e (1,2). Therefore, the workfront is 2000m and five excavators will be assigned a block length of 400m each. Using the box-cut on bench 3 the workfront are (3,3) and (2,3) which gives a total workfront of 2000m. This continues until bench No.8. At bench No.8, the workfront is maximum and equal to 7000m requiring 18 excavators. Thereafter, the workfront begins to decrease to 6000m on bench No.9, 5000m on bench No.10 and so on (table 1). This requires that the block length for each excavator be adjusted (reduced) to accommodate all the excavators used on bench 8. Therefore the deepening rate becomes higher and bench extraction time reduces.

For each pushback, the deepening rate and extraction time is estimated using the following formula (Nwosu 1994).

$$h_r = \frac{nQ}{hLB(\cot\varphi + \cot\beta)}$$ *modified from Arsentiev 1970*

Where;

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

Q = extraction equipment annual throughput

h = bench height

L = block length

φ = operating angle

B = width of bench working room

β = pit deepening angle

h_r = annual pit deepening rate.

Using the deepening rate and bench height of 10m, the extraction time for each pushback was established using the following formular

$$T_{ex} = \frac{h}{h_r}$$

Where;

T_{ex} = extraction time for each pushback

In the analysis, the life span of each excavator is assumed 10yrs. Any excavator that works up to 10yrs is regarded as unavailable and may be replaced or not. If the excavators are replaced by new ones, the number is designated +3 for example. If the excavator is unavailable but not replaced, then the number is designated -2. In this case, the length of block for each excavator is adjusted to suit the number of available excavators. This leads to increase in the length of block and deepening rate reduces while extraction time for each bench increases. Thus, change of block length depending on the available number of excavators can be used for mine closure planning. If it is required to add more excavators to meet up with expanding workfront and these excavators cannot be utilized within the entire life of the mine, and mine management has no other property to deploy the equipment, the existing excavators in the mine can be made use of by adjusting the block length. This is more so if this will not lead to extension of the life span of the pit to the point that it substantially affects the NPV of the project.

Table 1: Computation of pit parameters and equipment deployment

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

2. DISCUSSION

The criterion of maximum profit per ton of total material can be applied to define the positions of the box-cuts at each bench, both for simple and complex deposits. The geometrical modelling of extraction processes which takes off from the position of box-cut defined by the mining sequence can be used to estimate the number of equipment required at each stage of mining operation. Furthermore, this process can be used to ensure that mine management manages its equipment fleet in such a way as to ensure that at the point of closure of the mine, all equipment would have served their full life span. Thus, the above method can be used for mine closure planning.

3. CONCLUSION

Fig 3 shows the locus of movement of the box-cuts. As can be seen, the box-cuts are positioned towards the left side of the cross-section, thus avoiding the encroachment into areas with high stripping ratios. It then goes to show that the criterion of maximum profit per ton of total material also ensures minimum stripping ratio suggested by A.I Arsentiev (1970). However, the criterion of maximum profit per ton of material is easier to construct and displays the profit field for easy decision making. Also, in complex deposit consisting different types of ore, metals and grades, the minimum stripping ratio criterion cannot be applied (Halodnikov 1987).

The use of geometrical modelling and analysis to decide the number of excavators is more realistic because it is based on technical possibility. More so, it shows which time in the life of the mine the equipment are required to be bought. The cumulative extraction time of all the benches gives the life span of the mine

4. REFERENCES

[1]. Arsentiev A.I (1970) Pit Limit and Production Rate Estimation. Nedra Publishers Moscow.

[2]. Arsentiev A.I and Halodnikov G.A (1990) Open Pit Mine Limit Estimation of Complex or Deposit.

Quarterly of Department of Surface Mining. St. Petersburg Mining Institute Russia.

[3]. Albor F.R and R. Dimitrakopoulos (2010) Algorithmic Approach to Pushback Design Based on Stochastic Programming: Method, Application and Comparison, Mining Technology. Journal of Australian Institute of Mining and Metallurgy.

[4]. Nwosu J.I (1994) Optimum Pit Limit Design and Production Rate Estimation for Complex Ore Deposits.

Unpublished Ph.D thesis, St. Petersburg Mining Institute (Technical University) St. Petersburg, Russia.

[5]. A.S Arayo, M. Nehring, E.T Vegh, N.S Miranda (2020) The Impact of Equipment

Productivity and

Pushbacks Width on The Mine Planning Process. Journal of South African Institute of Mining and Metallurgy.

[6]. Daniel Kraznovic Nenad Vusovic, Milenko Ljubojev (2018) Selection of The Optimum Pushbacks in a Long-term Planning Process of the Open-pit – A Condition for Maximization of the Net Present Value: A Case Study, The Open-pit Veliki Krivel, Serbia. Mining and Metallurgical Institute BOR.

[7]. Ramazan and Dagdelen (1996) Pushback Design Algorithm in Open-pit mining. Colorado School of Mines.

[8]. Xianwei G.U., Qing Wang Xiaochuaxu, and Xiaoqian (2021) Phase Planning For Open-pit Coal Mines Through Nested Pit Generation and Dynamic Programming. Mathematics Problems in Engineering (2021).

Nwosu J.I. "Mine Sequencing and Equipment Deployment Planning For Open-Pit Mining Of Steeply Dipping Ore Deposit." *IOSR Journal of Engineering (IOSRJEN)*, 12(04), 2022, pp. 01-07.