Best Positive Inverted Truncated Cone – BPITC – Method and Its Application for Optimum Pit Design and Strategic Production Planning

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Abstract: The design, production planning and scheduling of an open pit mining project can only be started after the ultimate pit limit (UPL) has been determined. UPL determination is affected by input factors such as metal price, slope stability and grade uncertainty. Metal price fluctuations for example have imposed a high degree of uncertainty to the mine planning procedure, whereas slope instabilities accounts for majority of mining accidents and excavation downtime. These factors all contribute to the difficulty in determining the optimum design and sequence of mining. In a bid to tackle the aforementioned problems, a non- mathematical formulation model with pit slope constraints, metal price fluctuations and dynamic cut-off grade is introduced. None of the existing algorithms consider these factors and the time value of money collectively in UPL determination; this study aims to determine UPL, mine design, mine schedule and strategic long-term plan using the Best Positive Inverted Truncated Cone (BPITC) algorithm. We implemented this algorithm on a metallic ore deposit. Results confirmed that it guarantees the true optimum UPL while some commercially available software packages may not.

Keywords: *Ultimate Pit Limits (UPL), Decision-Making, Production Planning, Best Positive Inverted Truncated Cone (BPITC), Strategic Production Planning*

Introduction:

Conventional open pit mine production and scheduling requires a group of activities to be performed and decisions to be taken by mine planners, such as optimizing the pit with nested pits, pushback designs, blending and cut-off grade determination (Beretta & Marinho, 2015).

Mine optimization techniques could be categorized as deterministic and uncertainty based. Deterministic techniques include the Dynamic Programming (DP) approach, Mixed Integer Programming (MIP), Linear Programming (LP) model and Meta-heuristic techniques. Any of the above deterministic techniques manipulate a given geological block model to define an ultimate pit limit using either the moving cone method, or Korobov algorithm, or the Lerchs-Grossman (LG) technique. Many researchers have investigated and published papers on the subject of ultimate pit design algorithms, both in the heuristic category, such as the Positive Moving Cone (PMC) algorithm; and in the mathematical category such as the graph theory algorithm, linear programming, and maximum flow algorithms to name but a few.

For the past five decades, the mining industry has not yet been able to fully solve the problems associated with pit optimization. Our research is based on the DP principle using the moving cone technique. Our concept for ultimate final pit shape in open pit mine design and optimization uses the Best Positive Inverted Truncated Cone (BPITC) algorithm.

The algorithm is not a mathematical formulation; rather it's a sequential approach to mine optimization involving a series of calculations that lead to optimality.The algorithm is purely based on the principles of the moving cone technique with excavations from bottom to top instead of the reverse, a technique called Best Positive Moving Cone (BPMC). In this research, we modified the idea behind BPMC by truncating the cone. This modification was made because in any mining operation it is difficult, if not impossible, to mine at the tip of the cone due to equipment size and slope angle stability.

BPITC makes excavations starting from the lowest level towards the top. It initially mines maximum positive pits in a mining area and then continues to survey within the mine area. It decides the size, position, and depth of the cone with maximum benefit and then iterates the same procedure throughout the mine area. This technique guarantees that mining and milling constraints are satisfied in each period, because the effect of pit volume on the unit cost is also considered.

We implemented the algorithm on a metallic Iron ore deposit using a computer of 8GB RAM, Core i5 and CPU @3.10 GHz. The algorithm source code was used written in FORTRAN.

Obtained results confirmed that this algorithm guarantees the true optimum UPL while some of the commercially available software packages may not.

Principles of the Inverted Truncated Cone:
Theoretically, this algorithm can be simply explained as outlined in the phases below:

Phase 1: Assess value for cone of the lowest block, in the biggest possible pit. If the value of the lowest block for the cone is negative, leave the negative block un-mined. Otherwise, if this block is positive, then mine it; the sub, or intermediate, pit will then be visible, displaying the respective pit topography.

Phase 2: Evaluate other blocks on the lowest level and repeat Phase 1. Otherwise, move to Phase 3.

Phase 3: Proceed to subsequent levels upward, each time, repeat Phases 1 and 2 until the top level of the block model has been reached.

This algorithm is a modified concept of the BPMC technique. However, there is a notable difference between the two techniques. BPMC finds and mines the maximum pit using a cone, whilst BPITC finds and mines the highest pit value (PV)using a truncated cone as depicted in figure 1. The approach adopted in the BPITC algorithm simultaneously determines an ultimate pit of a mine, and an optimal block extraction sequence that maximizes NPV; BPITC specifies whether a block should be mined or not using the following constraints; slope angle, truncated distance, mining and processing costs, and cut-off grade.
From this principle we can summarize the distinctive features for BPITC in two ways:
(I) BPTIC finds the maximum PV, and (II) optimizes the truncated variable distance.

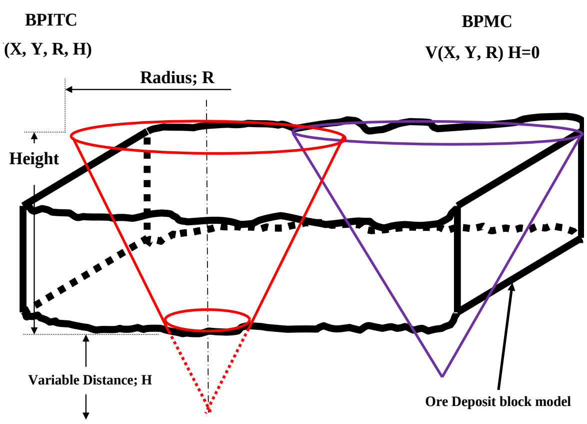


Figure 1 - Distinction of BPITC from BPMC

Pit Optimization and Block Sequencing using BPITC:
Figure 2 shows the flowchart of the BPITC source code. At the start of the program, after declaring the variables, input cost parameters, block dimension and density, concentration parameter for cut-off grade and price coefficient, the code reads the surface topography files for top and bottom elevations. First, it reads the lower elevation followed by the top elevation contour files in a specified ASCII format, and then closes the files. After reading the surface topography files, it will create a boundary in order to discard the un-necessary blocks, often referred to as air blocks outside the range of the block model.
The next step will be to read the file that contains the block model. If the data file does not conform to the acceptable ASCII format, an error will be issued and the program terminates with a terminal error message. If it follows the correct formatting, then the code will start the loop simulations on the block model and identify the column that has the mineral grade attribute, based on the input directives.

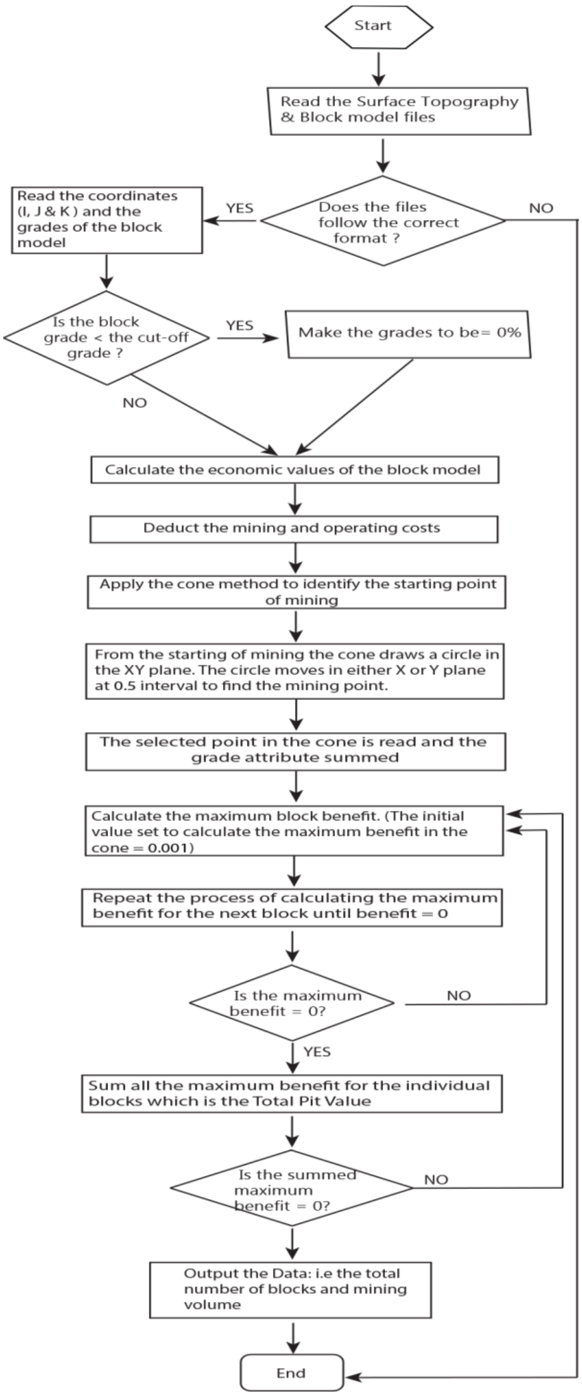


Figure 2 - Flowchart of the source code

The simulation process continues and applies the cut-off grade calculation method, either based on the metal price or price coefficient method. At this point, if the mineral grade is less than the cut-off, then, the program assigns 0% to that grade and calculates its economic value based on the assigned digit. Else, it calculates the economic value based on the actual block grade. Upon meeting all the required conditions, it proceeds to calculate the economic value of the grade attribute at each block.

At this stage, upon request, it will output the calculated economic value of each grade in the block model. With the economic values calculated, the cone method will then be applied to identify the starting point for mining. Before determining the starting point of mining, the central point of the cone must be determined.

In determining the cone's central point, two points are selected within the cone with point 1 at P (X, Y & Z) and point 2 at P2 (X_c, Y_c, & Z_c). The distance between these two points is given in equation 1. This relation coded in the program, finds the center of the cone. This process is illustrated in Figure 3.

$$D = \sqrt{(X - X_C)^2 + (Y - Y_C)^2 + (Z - Z_C)^2} \qquad (1)$$

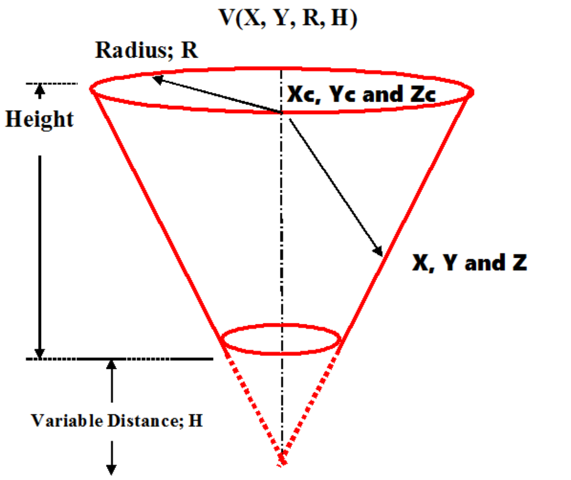


Figure 3 - Depiction of how the center of the cone is determined

The next step in the calculation process will be to determine the starting point of mining. The slope of the cone developed is 45º. From the calculated radius of the cone, it draws a circle in the XY plane and the centre of the circle will move in either X or Y planes every 0.5m to find the point to start mining.

After determining the central point and starting point of mining, the moving cone formula is applied on the grade value of the selected point, and calculates the benefit that could be obtained from mining and milling the grade in that block. To calculate the maximum benefit for blocks in the cone that will be within the ultimate pit, the initial benefit value is set to 0.0001. Upon completing calculations for the grade of the first point, it continues to find the maximum benefit for the next grade value and repeats this procedure until the benefit equals 0.

The first identified block in the calculation process is the point in the pit with maximum benefit; it is also the starting point of the sequencing process. All possible ways to sequence blocks are examined and the optimum sequence determined through the benefit (NPV) calculation. This procedure continues until no block is needed to be removed from the pit.

Case Study:

In this study, we considered an Iron-Ore deposit discretized into mining blocks of 10 x 20 x 9 m^3. Figure 4 shows the plan view of the geological drilling map and the block model obtained. We did pit optimization and production planning using the BPITC method on the block model.

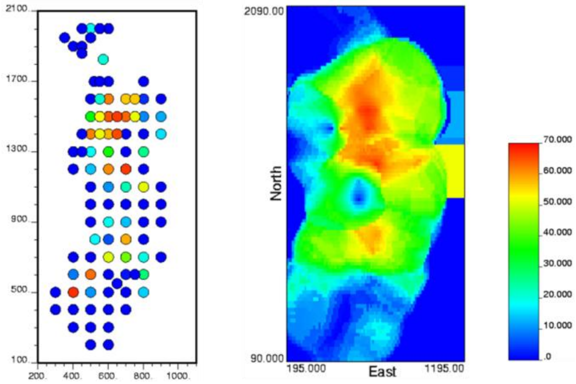
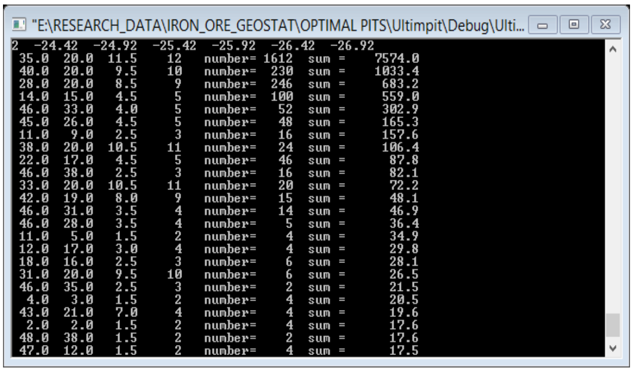


Figure 4 Drillhole plan and block model

Results and Discussion:

BPITC optimizing algorithm was applied to optimize the block model. The optimized model gave rise to pit topographies whose data was then used to develop visible 3-D ultimate pits. Figure 5 shows the calculation and mine schedule running on the command line terminal, resulting from executing the source code after compilation. A mine sequencing file was output from the program

The lines in the output file and also as seen from figure 5 are as follows: (from left to right) X, Y and Z (depth) coordinates of the blocks to be extracted, number of pits per sequence, number of blocks contributing to each pit, and the net profit generated from extracting any particular pit.



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"E:\RESEARCH_DATA\IRON_ORE_GEOSTAT\OPTIMAL PITS\Ultimpit\Debug\Ulti...
2  -24.42  -24.92  -25.42  -25.92  -26.42  -26.92
 35.0  20.0  11.5   12   number= 1612  sum =   7574.0
 40.0  20.0   9.5   10   number=  230  sum =   1033.4
 28.0  20.0   8.5    9   number=  246  sum =    683.2
 14.0  15.0   4.5    5   number=  100  sum =    559.0
 46.0  33.0   4.0    5   number=   52  sum =    302.9
 45.0  26.0   4.5    5   number=   48  sum =    165.3
 11.0   9.0   2.5    3   number=   16  sum =    157.6
 38.0  20.0  10.5   11   number=   24  sum =    106.4
 22.0  17.0   4.5    5   number=   46  sum =     87.8
 46.0  38.0   2.5    3   number=   16  sum =     82.1
 33.0  20.0  10.5   11   number=   20  sum =     72.2
 42.0  19.0   8.0    9   number=   15  sum =     48.1
 46.0  31.0   3.5    4   number=   14  sum =     46.9
 46.0  28.0   3.5    4   number=    5  sum =     36.4
 11.0   5.0   1.5    2   number=    4  sum =     34.9
 12.0  17.0   3.0    4   number=    4  sum =     29.8
 18.0  16.0   2.5    3   number=    6  sum =     28.1
 31.0  20.0   9.5   10   number=    6  sum =     26.5
 46.0  35.0   2.5    3   number=    2  sum =     21.5
  4.0   3.0   1.5    2   number=    4  sum =     20.5
 43.0  21.0   7.0    4   number=    4  sum =     19.6
  2.0   2.0   1.5    2   number=    4  sum =     17.6
 48.0  38.0   1.5    2   number=    2  sum =     17.6
 47.0  12.0   1.5    2   number=    4  sum =     17.5
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Figure 5 - Optimal pit value calculation and pit sequencing.

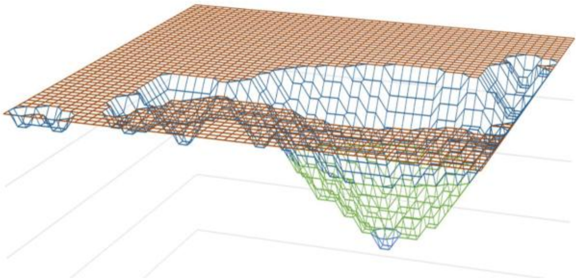

Figure 6 - Pictorial representation for designed 3-D ultimate open pit model

Figure 6 shows a pictorial representation of the 3- D ultimate pit shell. In determining the pit outline using the truncated cone method, bounding techniques were applied to discard the un-necessary blocks often referred to as air blocks. Table 1 shows the ultimate pit design summary.

Table 1
Ultimate pit design summary

Pit Summary	Values
Block Size (m^3)	87500
Optimum Pit Value ($)	11300
Positive blocks in pit	1750
Negative blocks in pit	767
Number of Air blocks	0

A common drawback of the BPITC algorithm is that, even though it considered the dynamic concept of cut-off grade, a long time is needed to produce reliable results; therefore, when implemented on a PC for large ore bodies, it will consume a lot of time. In this research, it took about 5 hours to design and optimize a model with 420,000 blocks. However, as the number of blocks increases so will the time required to optimize depending on the computer specifications.

Also, the optimal scenario is always affected by uncertainties related to the input data, and most, if not all, optimizing algorithms, including this one, do not consider these uncertainties during the optimization process. Some of the uncertainties include mining specification, and economic uncertainties.

Conclusion:

The BPITC optimizing scheme, a non- mathematical optimization algorithm, was used to optimize the generated resource model for an Iron-Ore deposit. The results obtained by BPITC show that it can simulate optimal solutions for final pit outline of the Iron-Ore deposit, and it gives effective information on mine sequencing and project decision-making.

Even if the BPITC scheme gives the best and true optimal solutions to open pit mine planning and design, it has limitations of not realizing the true time value of money, this factor makes it less reliable over time. However, it does consider the uncertainties associated with grade variability, slope constraints and dynamic cut-off grade. The achieved formulation and methodology can be adjusted and used for all kinds of deposits.

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