Capacitated final pit definition

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ABSTRACT

In open-pit mine planning, the definition of final pit limits is a crucial decision with a strong impact on economical profit. There is a set of technical and economical variables that should be considered in this calculation, such as slope stability angles, prices, mining costs, processing costs, metallurgical recovery, among others. However, an important strategic decision, which is mining rate, is not considered by traditional methodologies in the definition of final pit limits, despite of its importance and the implication of this variable in the timing of cash flows, investments and in mining business results in general. This is, at high mining rates, cash flows are received early but investments in processing plant and equipment are high too, and vice versa, this generates a trade off that the optimisation process must consider and tackle.

This paper discusses a new methodology that has been developed regarding to this matter. It is an iterative process of final pit calculation using an improved algorithm based on Lerchs-Grossman (1964) integrating block sequencing and scheduling heuristics introduced by Gershon (1986), and taking into account the mining rate that defines the production plan.

INTRODUCTION

One of the biggest problems currently and historically affecting the mining business are decisions such as: final pit size in the case of open pit mining, exploitation rates, quantity, size and shape of pushbacks or phases, among others. These are directly affected by the quantity and quality of information, how to understand this information, and the planning and strategic profile of the mining company.

For these reasons, it is understood that open pit mine planning must at least address the following issues: final pit size, mining geometries and production rate; estimating extraction rates depending on strategies and decision making, being the final pit decision one with high impact on investments and operating results due to the chain of implications that entails. One question that should be answered is which final pit should be chosen for a given mining rate?

METHODOLOGY

The methodology is basically a set of interconnected modules to implement the following calculation of capacitated final pit:

1. Final pit calculation using the Lerchs and Grossman algorithm (LG initial final pit)
2. Calculation of positional weight or 'key-value' using the inverted cone block sequencing heuristic introduced by Gershon (Gershon Heuristic)
3. Definition of the extraction sequence block by block according to the positional weights and respecting the precedence constraint between blocks (Mining Sequence)
4. Application of discount to the in situ block value depending on the mining period (Discount Rate).
5. Next iteration of final pit calculation using (LG final pit) is performed considering now the discounted block values incorporating time of extraction to this calculation.
6. Back to step 2 for positional weight calculation or 'key-value' with time discounted values.

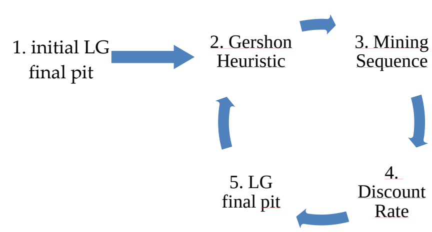

Figure 1 Components of final pit definition

The Gershon referenced heuristics correspond to the calculation of the sum of block values included into the inverted cone under each block, thus, it is a measure of the relative importance of extracting each block according to the blocks that would be free to extract. This is seen in the following figure.

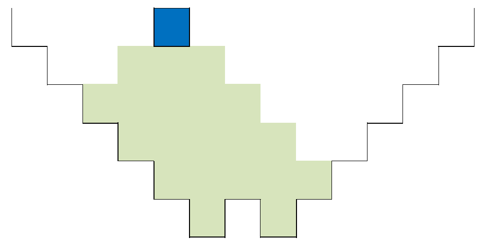

Figure 1 Gershon positional weight heuristic or 'Inverted Cone'

CASE STUDY

The case study is done on a block model with the following characteristics:

- Number of blocks: 62,200
- Block size: 30 x 30 x 30 m^3
- Products: Cu, Au

The slope angle constraint is represented by setting precedence of the five blocks located in the 'cross' above the block, as shown in the following figure.

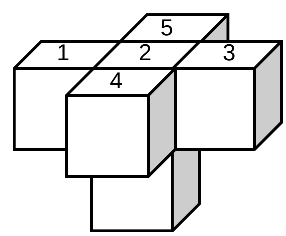

Figure 2 Precedent blocks in cross scheme

The algorithm for calculating the positional weight according to Gershon heuristic was performed on each block considering the inverted cone containing the strict successors of the block, included within the pit envelope calculated in the previous step.

Considering this positional weight or 'Gershon Value', a Greedy mining algorithm is performed to get an extraction order or mining sequence. This means that the mining sequence is based on the relative importance for each block to be extracted.

For the convergence study, the following configuration settings were adopted: runs were performed for mining rates in the range between 100 and 1000 [blocks/period] with a step of 100 [block/period] between one run and another, *i.e.* ten production capacity scenarios were studied.

Finally, based on the mining sequence, and the time period of extraction of each block as a result of the mining rate, the discount is applied over the value of each block with a rate of r = 10%, depending on the period τ in which you remove the block , this is, the traditional form $\rho = \frac{1}{(1+r)^{\tau}}$

In each run for different capacities, the first iteration corresponds to the classic run of Lerchs-Grossman on the entire universe of blocks without any discount for extraction period, that is, each iteration "*iter0*" is the same for different conditions of mining rate (100 to 1000 blocks/period), so a ratio that shows the behaviour of the production capacity or mining rate *vs.* reduction in final pit dimensions can be calculated. This relationship, directly calculated from final pit tonnage (as a percentage of the "*iter0*" pit tonnage) and the mining rate shows increasing asymptotic behaviour as might be expected with the limit on the 100% of the final pit size of the standard LG run.

RESULTS AND ANALYSIS

The following figure is a vertical section showing the impact of performing the iterations: blocks are tagged with the number of the iteration that it belongs to. Those with number 6 are extracted in iterations 6, 5, 4, 3, 2 and 1, so it is possible to check the decreasing in geometry along the different iterations.

Rót	3475	3505	3535	3565	3595	3625	3655	3685	3715	3745	3775	3805	3835	3865	3895	3925	3955	3985	4015	4045	4075	4105	4135	4165	4195	4225	4255	4285	4315	4345	4375	4405	4435	4465	4495	4525	4555	4585	4615	4645	4675	4705	4735	4765	4795	4825	4855	4885	4915	4945	4975	5005	5035	5065	5095	5125	5155	5185	5215	5245	5275
735	0																																																												
705	0	0	0	0	0	1	1	1	1	1	1	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6																	0		0	0	0	0	0	0	0	0	0
675	0	0	0	0	0	0	1	1	1	1	1	1	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
645	0	0	0	0	0	0	0	1	1	1	1	1	1	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
615	0	0	0	0	0	0	0	0	1	1	1	1	1	1	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
585	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
555	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
525	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	6	6	6	6	6	6	6	6	6	6	6	6	6	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
495	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	6	6	6	6	6	6	6	6	6	6	6	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
465	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	6	6	6	6	6	6	6	6	6	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
435	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	6	6	6	6	6	6	6	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
405	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	6	6	6	6	6	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
375	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	6	6	6	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
345	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	6	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
315	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
285	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4 Pits over iterations. Case mining rate 100 [blocks/period]

Once the runs are complete, the first results show that there is a clear relationship between mining rate and change in the final pit size and tonnage compared to the traditionally calculated with Lerchs-Grossman algorithm ('*iter_0*'). As shown in the following graph, there are mining rates that reduce size of final pit.

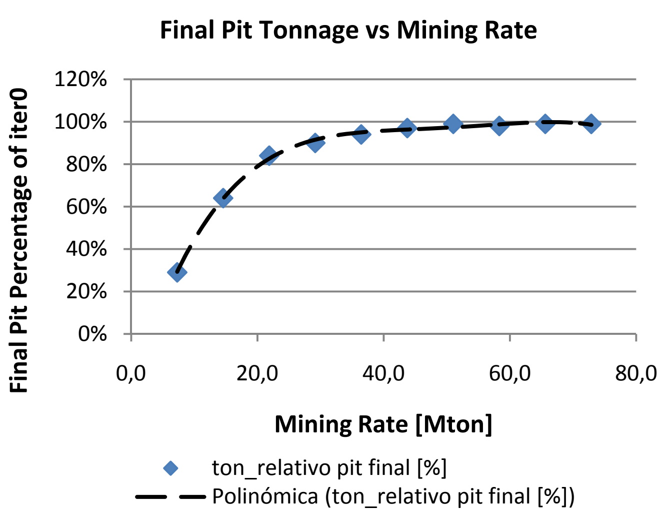

Figure 3 tonnage of final pit relative to initial LG calculation, for different mining rates

In particular the ratio of the total tonnage and mining rate is calculated, so there is an approximation of the number of periods that correspond to mining at that rate. This number will be called *Periods_0* periods. The latter, in turn, have implications for the impact that the discount rate as a modulator of the values of the blocks extracted during the life of the mine, *ie* the lower the mining rate of the run, the greater the number of *Periodos_0* for the mining rate, and the greater the impact of the discount rate for the last periods provide less and less value and therefore the size of the pit will be less caused by the decreasing potential for a single block to lift the preceding cone.

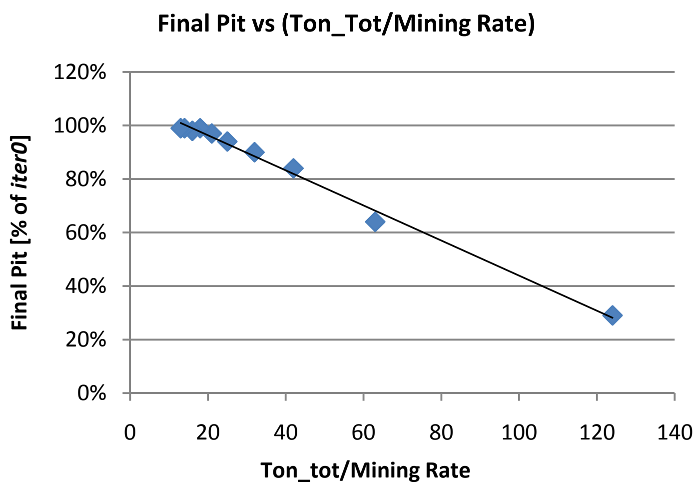

Figure 4 Relationship between mining rate and size of final pit

Finally, once performed the runs for every mining rate, there is a set of nested pits as a result of the capacities conditioning the evaluation, as shown in the following figure:

Ró	3625	3655	3685	3715	3745	3775	3805	3835	3865	3895	3925	3955	3985	4015	4045	4075	4105	4135	4165	4195	4225	4255	4285	4315	4345	4375	4405	4435	4465	4495	4525	4555	4585	4615	4645	4675	4705	4735	4765	4795	4825
705	500	300	200	200	200	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100												
675		500	300	200	200	200	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	200	200	200	200	200	200	300	300	400	500	700
645			500	300	200	200	200	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	200	200	200	200	200	200	300	300	400	500	700	
615				500	300	200	200	200	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	200	200	200	200	200	200	300	300	400	500	700		
585					600	300	200	200	200	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	200	200	200	200	200	200	300	300	400	500	700			
555							300	200	200	200	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	200	200	200	200	200	200	300	300	400	500	700				
525								300	200	200	200	200	100	100	100	100	100	100	100	100	100	100	100	100	100	200	200	200	200	200	200	300	300	400	500	700					
495									300	200	200	200	200	100	100	100	100	100	100	100	100	100	100	100	200	200	200	200	200	200	300	300	400	500							
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315															300	200	200	200	200	200	200	200	200	200	300	300	400	500													
285																300	200	200	200	200	200	200	200		300	400	500														

Figure 5 Capacitated final pits for different mining rates

CONCLUSIONS AND RECOMMENDATIONS

Assumptions about pit size are fulfilled with remarkable clarity when the capacity variable is added as a part of the global problem. This is, as the mining capacity is increased, which is in general a consequence of expanding the mining system or plant constraints; then the pit size also increases. This behaviour has an asymptotic limit when a certain capacity is reached, and the pit size becomes closer to the traditionally calculated LG final pit. It is easy to see that if the capacity in a single period is greater or equal to the total tonnage of the initial pit, then the whole pit will be extracted in the period zero, and there will be no discount on the block values and therefore there will not be any change in the calculation of the new LG final pit.

As shown by the extended results, it takes generally less than six or seven iterations, to converge to a better solution for a given mining rate, so one strong recommendation is that, despite the scheduling methodology applied in the mine planning procedures, a discount rate should be incorporated depending on the scheduling to the block values iterating as described in this paper because it impacts in a very positive way on the economic envelope, the mining design and sequence, and most important of all in the NPV of the project getting close to a holistic mine planning.

The problem gains a new dimension different from the traditional analysis taking a step toward an understanding of the problem in its fullness because it is information that was previously unknown and therefore it was not considered to support any decision.

The next step the authors seek to achieve is to introduce the methodology into the traditional planning mechanism to conduct the open pit mine planning, which can be established as a branch of evaluation and analysis consistently with the procedures used and validated into the industry.

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