Impact in long-term planning of optimization algorithms and mineral deposit geometry

Impacto de diferentes algoritmos e geometria de depósitos minerais no planejamento de longo prazo

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Resumo

O principal objetivo do planejamento mineiro é determinar a distribuição de quantidade e qualidade do minério ao longo de uma sequência de tempo, ou seja, minério necessário para tornar o projeto técnica e economicamente viável. Esse sequenciamento é fundamental para o sucesso financeiro de uma atividade de mineração e, atualmente, esse sequenciamento ideal pode ser obtido através de vários aplicativos computacionais de mineração. A maioria dos estudos em planejamento de lavra apresenta a cava final calculada por um único algoritmo escolhido pelo engenheiro de projeto ou, simplesmente, por disponibilidade. Além disso, variações nos aspectos técnicos e geométricos do projeto podem ser impostas provocando diferenças nos resultados. Existem muitos algoritmos implementados em diversos programas comerciais para o cálculo da cava final e sequenciamento de longo prazo, e, por isso, um dos objetivos desse trabalho é verificar a eficácia dos algoritmos que obtiveram maior reconhecimento dentro da indústria mineral e verificar se existem diferenças relacionadas com o tipo de mineralização e depósito onde eles são aplicados. A comparação é realizada usando dois programas comerciais e dois algoritmos diferentes para determinar se as diferenças podem ser observadas para tipos de mineralização distintos. A aplicação da metodologia foi executada em modelos de blocos tridimensionais estimados e os resultados analisados para os três tipos de depósitos: um corpo de minério de cobre disseminado, um grande depósito de fosfato de origem ígnea e uma mineralização aurífera, de espessura pequena relativamente à extensão em profundidade, apresentando um mergulho subvertical.

Palavras-chave: Planejamento de lavra, algoritmos de otimização, longo prazo.

Abstract

The main objective of mine planning is to determine ore quantity and quality distribution along a time sequence, i.e., scheduling the ore necessary to make the project technically and economically feasible. These temporal sequences are fundamental for the financial success of a mining activity and currently this optimal sequence can be obtained through various mining software. Most studies in mine planning present the final pit calculated by only one algorithm chosen by the mining

engineer or simply by availability. Besides, technical constraints and geometrical aspects can be imposed promoting differences on the results of the project. There are many algorithms implemented in various commercial software for the ultimate pit calculation. One of the purposes of this work is to check the effectiveness of the algorithms that obtained greater recognition within the mineral industry and if there are differences related to the type of mineralization and deposit where they are applied. The comparison is performed using two commercial software, and two different algorithms to determine if differences can be observed from the different mineralization types. The implementation of the two algorithms in three-dimensional block models estimated and analyzed for three types of deposits: a massive disseminated copper orebody, a large igneous phosphate deposit and a subvertical gold vein type.

Keywords: *Mine planning, optimization algorithms, long term.*

1. Introduction

The optimization in open pit mines is an important element to successfully achieve the realization of the project. The pit that provides the best profitability is made by optimization algorithms, considering a specific economic scenario and, at each change of this scenario it becomes obsolete and should be re-examined (David et al., 1974; Dagdelen, 2001; Halatchev, 2002). The method widely used to represent mineral deposits is the individualization in portions of the deposit in a Cartesian representation called block model. This model is essential for the pit optimization process and stores technical and economical parameters to determine the economic value of each block that will be analyzed by optimization algorithms. Over this model will be calculated the profit function so that one can quickly have their parameters changed for sensi-

tivity studies.

In this work were used two algorithms with the implementations of the Lerchs-Grossmann (LG) algorithm (Lerchs-Grossmann, 1965), a dual simplex algorithm that examines the maximum closure problem and minimum cut amount that seeks the optimal solution possible (Tolwinski, B. and R. Underwood (1992), Underwood, R. and B. Tolwinski (1996) Underwood, R. and B. Tolwinski, 1998). Its relationship to maximum flow is quite obvious (Do Carmo, 2001) and Floating Cones (FC) (Pana, 1965); a method based on optimal contour search final pit attempts. The principle of the algorithm considers the physical constraints and local geological restrictions (Guimarães, 2007). The two techniques were applied in three separate ore deposits to assess the performance in reproducing the results for

different deposits, evaluating the processing time to calculate the mathematical pit and in a second step to sequence different deposits according different constraints.

The main differences observed in the construction of final pit were: variation in grade of pit, total quantity of ore and waste, computation time. Mining sequencing was set to control certain parameters in each phase (either ore or contaminants). There were observed amount of ore and waste by phase, differences in mining sequence, stripping ratio, processing time and level of user control and interaction.

In this sense, the purpose of this study is to submit the three databases representing deposits with different geometries to two algorithms extensively used in the mining industry and analyze comparatively the results produced.

2. Material and methods

Description of mineral deposits

The first model consists of a large copper and molybdenum disseminated deposit. The data were obtained by drill hole samples within a file containing location in three dimensions, hole depth, slope and azimuth and another file grade containing copper and molybdenum assays, rock type and density of each sample.

The second model refers to a relatively small gold deposit comprised of an high dip ore body of with average gold grades of approximately 1 g/t, due to selectivity and dilution, the block size adopted for this deposit was relatively small, using a dimension to the ore zone of 5 x 5 x 5 m and for the waste zone the block size used was 25x25x5 m.

The third deposit studied consists of a large phosphate deposit, an igneous alkaline complex divided into weathering zones, containing a set of oxides where the quality of the primary attribute is measured by the apatite content (P2O5). The average grade of the deposit is about 10% of apatitic phosphate (P2O5AP).

Methodology

In the first step, the models were imported into the two mining softwares, containing different optimization tools, referred in this work as softwares A and B. As the goal of the work is not

to compare the commercial programs itself but the optimization algorithms and its implementations and the form of sequencing, the programs will be referred here only as softwares A and B.

In program A, it is available only one optimization technique: the dynamic programming algorithm using Lerchs-Grossmann (LG). In Program B are available the Lerchs-Grossmann

and Floating Cones (FC) algorithms. An attempt was made to use exactly the same parameters in both programs which have different interfaces and complexities to input data, to maintain comparability in the results.

Despite the interface, the two programs present differences in format and data insertion order, although one realized that the two programs require similar parameters to run the algorithm.

In this way, knowing whether the block is mined, or in other words, if a block is contained in the proposed solution by optimization algorithm is of extreme importance (answer given by the optimization algorithm). But knowing when this block will be mined and later when this block will be sent to the process is even more relevant information, because this order defines the project's cash flow (Whittle, 1988).. Thus, the pits resulting from optimization for each deposit studied are divided into stages which will be used as precedence information to sequence the blocks in each software.

In program A, the mining sequencing was executed in two steps, at first, one obtained the phases of sequencing by the program A itself, i.e., were selected the phases by maximizing Net Present Value (NPV) criteria. In the second step, were used the phases created in program B, and inputted in program A to compare the results.

In the first case, the phases were obtained by selecting only a maximum number of stages and defining the criteria of pit size and minimum number of blocks. Thus, the phases generated were chosen only by NPV maximization criterion, not being mandatory total extraction from one phase to begin the next phase.

In the second case, it was only changed the phases. The phases generated in program B were exported and imported into program A, after one followed the same procedures for sequencing the first case obtaining also a worksheet with the results that will be analyzed later.

In Program B were generated phases to sequence through a tool iterating calculation of intermediate pits to until reaching the ultimate pit defining adequate definition of operational advances, information necessary for the sequencing tool.

Thus, one can select the pits for phases extraction to sequence the production using program B. In this case were analyzed, stripping ratio and quantity and quality of the ore, within phases that were used as input parameters in the program B sequencer.

The next step is to start the sequencing tool of program B, for the three deposits. Thus, varying these parameters one can get the optimal sequencing for each type of deposit and ore.

3. Results and discussions

Optimization

The results are shown in Table 1 indicate the differences between programs A and B using the two algorithms represented by the parameters chosen by the study, such as: tonnage, net present value (NPV) and ore content.

In copper/molybdenum model three pits were generated by the two programs and one realized that the results between the algorithms implemented using both programs produced very similar results, even though can be observed a small detachment between the surfaces.

The optimum pit and the results generated for the phosphate deposit are quite similar for both programs and algorithms tested. Compared to other deposits tested, this better adherence between the optimization algorithms in function of the geometry of this deposit. Note that numerical results show, for this deposit where the mineralization is much more homogeneous and the geometric relationship of area (large) relative to the thickness (small) is quite expressive.

For the gold deposit the particularity is not exactly related to the mineralization itself, but in the selectivity required for this type of deposit. To represent the model within the zone of interest one needs small blocks well adherent to the contact zone. Operationally the way to handle this problem ends up with the reduction of the block size. In this case the block model for this deposit has different sizes of blocks for waste and ore. The model in the region defined as ore has dimensions of 5 x 5 x 5 m and waste blocks have dimensions of 25 x 25 x 5 m. Because of the amount of blocks that could be generated if blocks of 5 x 5 x 5 m were defined for all portions of the deposit, generating a huge amount of unnecessary blocks. An important aspect about this model is that the program B cannot handle (because it does not operate with sub-blocks feature) so different block dimensions demanded the use of smaller blocks of 5x5x5m and the economic value of each block had to be recalculated using the same parameters assumed for the profit function.

Table 1
Results of the pit optimization in the three deposits.

Software (Algorithm)		A (LG)	B (LG)	B (FC)		A (LG)	B (LG)	B (FC)		A (LG)	B (LG)
		Cupper and molybdenum				**Phosphate**				**Gold**	
Tonnes (t)	Ore	265.606.594	267.749.719	253.118.000	Ore (30)	550.997.262	522.575.000	525.230.000	High Grade	7.274.431	7.708.000
	Waste	334.188.281	330.991.250	340.405.000	Waste (20)	265.362.303	260.701.000	266.638.000	Interm.	458.479	476.000
					Waste (10)	330.109.350	325.733.000	332.445.000	Waste	23.061.264	22.918.000
Total (t)		599.794.875	598.740.969	593.523.000		1.146.468.915	1.109.009.000	1.124.313.000		30.794.174	31.102.000
NPV ($)		1.805.824.530	1.859.340.840	1.829.464.528		4.750.681.204	4.803.718.257	4.749.201.961		86.207.739	86.667.332
Ore (%)	Cu	0,863	0,855	0,861	P2O5AP	7,93	7,98	7,97	Au	1,05	1,06
	Mo	0,101	0,101	0,102							

Figure 1
Final pit (blue) for copper and
molybdenum deposit.

Sequencing

Copper and molybdenum

This sequencing has as main objectives a period of 20 years (that corresponds to the deposit exhaustion), the production of an amount of 13 million tons of ore per year and maintaining a stripping ratio approximately constant between 0.8:1 and 1.2:1.

First was analyzed using program A sequencing tools, maximizing the net present value. It was observed that after the seventh year the stripping ratio stabilizes in the target and maintains an average of 1.26: 1:0 pm within the whole period. The ore production remained constant throughout the se-quencing as well as the grades of copper and molybdenum.

In the next case discussed in program B, sequencing was generated using five phases and the restrictions imposed to the sequencer were the same as the previous case. However, the sequencer of program B is very strict regarding the selection of the phases. In this case, we can verify that the annual targets regarding to quantity and grades of copper ore and molybdenum were affected, however the stripping ratio became unstable, varying across the years. This was attributed to the very tight restrictions of the program. The phases defined for the sequencing did not reach the desired ratio in several attempts, but then through an interactive approach repeating the steps until you reach the appropriate sequencing targets.

In the last scenario the phases established in (B) were imported into the program and then sequenced with the same parameters. It was noted that the ratio reaches the goals proposed in the program A using the same phases used to feed program B. It can be seen in Figure 2 the comparison between the results of the two programs.
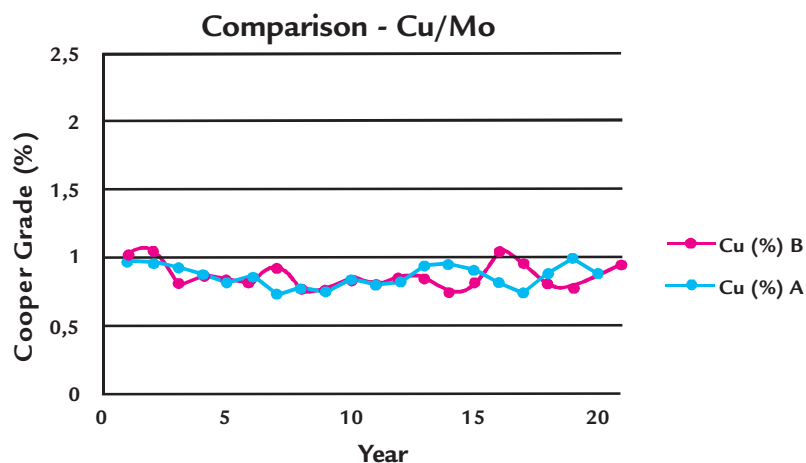

Figure 2
Comparison between programs
A and B, deposit of Cu/Mo.

Phosphate

The sequencing for the phosphate deposit was performed once again using the two programs used in this work. Unlike the two other deposits compared in this deposit it was not conducted the third scenario, placing the phases of the program B in the program A, because in this case only two phases were generated by program B.

This sequencing had as main objectives mining for 22 years (which corresponds to exhaustion of deposit), production of 25 million tons of ore per year and a stripping ratio around 1:1.

Analysis of sequencing using the program A and program B reach the restrictions applied to the case. We can see in Figure 3 the comparison between the two programs.

Gold

This sequencing has as main objectives mining for 16 years (until exhaustion of the deposit), ore production of 380.000 tons per year and keep a stripping ratio between 4:1 and 5:1. First it was analyzed the sequencing using the program A, so in this case one can observe that up to the twelfth year the sequencer followed the restrictions imposed between the limits of stripping ratio, the quantities of ore in the range of 380.000tons per year (tpy) and Au grade around 1 g/t.

In the next case will be addressed the steps using Program B, sequencing generated four phases and the restrictions imposed to the sequencer were the same as the previous case, sequencing deposit until exhaustion, production of 380 thousand tpy and waste/ore ratio between 4: 1 and 5: 1. In this case one can verify that the annual quantity of ore, 365 thousand tones, gold content in 1 g/t and stripping ratio in the 4: 1 to 5: 1 have been reproduced.

In the last scenario the phases established in (B) were imported in the program A and then sequenced by the program with the same parameters.

One can note that the amount of ore is maintained in 380.000tons, but the amount of waste and therefore the total mass movement, generating mining for 19 years and a stripping ratio with higher values. Figure 4 shows the comparison between the algorithms in the two programs.

Figure 3
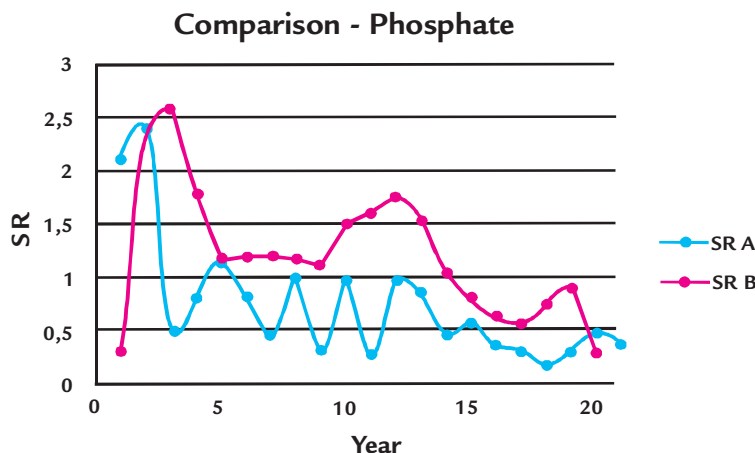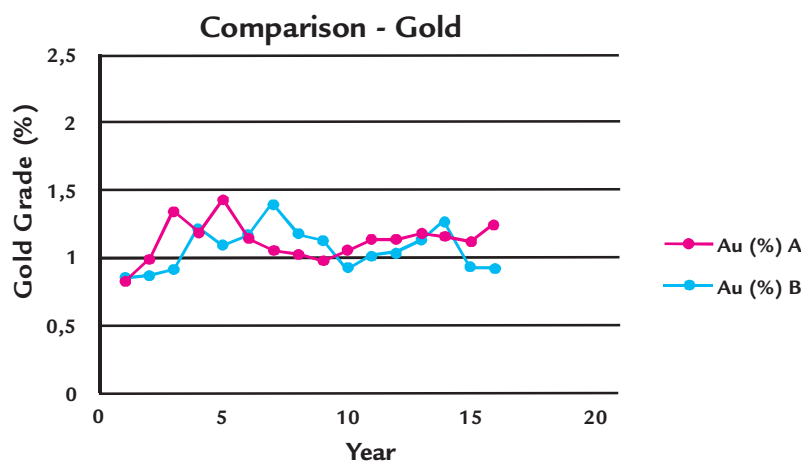Comparison between programs
A and B, phosphate deposit.

Figure 4
Comparison between softwares
A and B, gold deposit.

4. Conclusions

The main objective of this study is to present a comparison between the programs and algorithms of pits optimization and sequencing implemented within different mining programs. In this sense, different deposits were used, having different natures and geometries to test the applicability and the intricacies that exist between the programs and consequently between the algorithms itself.

Between the various comparisons carried out with the programs and algorithms were not identified significant differences to condemn or ostracize any of the algorithms in function of advantages that both present. Still, as the two algorithms have been used in three distinct types of deposits and the results have not shown significant differences, it is considered the extent of validity of application of both algorithms. In a context of long-term planning, several premises, assumptions and uncertainties are present. So that the order of magnitude of differences found may be treated as within this area of variation allowed for a future scenario of exhaustion of a deposit. It is recommended here that for an analysis that considers a first approximation, the algorithm of floating cones can represent an interesting alternative when the computation time for processing a deposit with huge number of blocks.

Altough this small difference observed when running the optimization and sequencing in deposits of copper/molybdenum and phosphate for the long-term planning can be diluted without affecting the mining plan. However, is important to stress that mining is an activity that works with large amounts of mass movement and small variations in pit optimization could represent a substantial amount of money.

About the sequencing, we found that the program A is much more flexible considering the definition of the phases, always seeking the highest net present value, while B is more rigid in relation to the defined phases, being easier to show the sequencing, but more complex to consolidate the phases correctly, especially when certain parameters of goal are defined as goal to be achieved. This means that there is a greater demand on the part of interaction from the planner for an appropriate selection of stationary targets within each phase for the long-term mine planning.

5. Acknowledgments

6. References

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