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ANALYSIS THE PROFITABILITY OF THE COPPER ORE EXPLOITATION ON THE CEROVO PRIMARNO-DRENOVA DEPOSIT FOR THE CAPACITIES OF FLOTATION ORE PROCESSING OF 6.0 AND 12.0 MILLION TONS ANNUALLY***

Abstract

The problem of exploitation planning refers to a criterion used to optimize the open pit. In spite of sophisticated algorithms, the problem of optimization is always an economic problem, within which the procedures for assessment the necessary economic parameters are defined. Every ore body is different, but the main steps in planning an open pit, when the main objective is to make a profit, are developed by the same principle. When planning the copper ore exploitation, the final economic result depends on the overall technological process of copper obtaining copper as a final product. This work presents an economic analysis of the copper ore exploitation on the Cerovo Primarno-Drenova deposit for the annual capacity of flotation processing of 6.0 and 12.0 million tons, using the software for economic analysis and long-term planning of open pits Whittle surface (Dassault Systèmes - Geovia).

Keywords: deposit Cerovo Primarno - Drenova, optimization of the open pit boundary, software Whittle, profitability of exploitation

1 INTRODUCTION

Profit is the dominant driving factor of modern mining. The process of globalization of the world market is especially pronounced in the sphere of production the mineral resources. The largest world mining investors, as a rule, develop the projects outside of their home countries, and the exploited mineral resources are most often the subject of a global market economy. Under the conditions of globalization over the years, the necessity of formation a unique methodology for evaluation the mining investment projects has been imposed. This is above all significant from the perspective of potential investors, who need a recognizable and verifiable methodology for evaluation the value of mining investment project, in order to collect the sufficient valid and reliable evidences of the economic justification of investment in the same. The developed methodology, which provides a unique and recognizable way to evaluate the value of investment mining projects, is in practice known as a conventional approach to the planning and economic evaluation of the mining projects.

Despite the expressed characteristics of each mining project (specific geological, technological, infrastructural, socio-economic, political conditions), a conventional

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approach, through a set of generally accepted procedures and formal techno-economic documents, provides an opportunity for a recognizable and comparable evaluation the economic value of the investment mining projects.

In implementation the optimization of the final contour of the open pit, in addition to the optimal contours also a set of additional contours is constructed. These additional contours are constructed as identical as the optimal contour, but one parameter (rarely) for defining the economic model is changed, resulting in generation the optimal contours different from the initial (nominal) one. In essence, an analysis of sensitivity the contour of the open pit to the parameter being changed is actually carried out this way.

When the final contour of the open pit is determined, it is necessary to define the order in which the blocks will be excavated inside the final contour of the open pit or to define the excavation dynamics. It can be viewed as the order of excavation by which the blocks should be removed during the lifetime of the open pit, in order to increase the total profit, in accordance with a series of operational-technological and physical constraints.

The aim of performed analysis is to define the optimal boundary of the open pit Cerovo Primarno-Drenova for the given techno-economic parameters and limitations of the flotation processing to 6.0 million tons (Variant I), or 12.0 million tons (Variant II), respectively.

The analysis was carried out using the software for economic analysis the long-term planning for development the open pits Whittle (Dassault Systèmes - Geovia). The following was processed within the analysis:

1) Optimization of the open pit.
2) Selection the optimal contour of the open pit for defined technical-economic parameters, terrain topography and existing innovative block model of the deposit.
3) Optimization the dynamics of ore and overburden excavation at the open pit.
4) Calculation the quantity of ore and overburden and Net Present Value in the optimal contour of the open pit.

In order to implement the optimization process in Whittle software, the expected mining costs of ore exploitation and processing to the level of concentrate of the useful component, as well as the total metallurgical costs for the final product or cathode, were first estimated.

As the software manipulates only with the attributes/values of the mini blocks from the block model of deposit, it is necessary to attach this time dependence to the mini blocks. This dependence was achieved on the basis of production limitations, i.e. limited capacity of the flotation ore processing.

To optimize the open pits, the economic parameters were used which include: [1]

- excavation costs per ton of excavations,
- processing costs per ton of ore,
- costs of metallurgical processing per unit of produced basic product – cathode,
- metal prices,
- discount rate.

In addition to the economic ones, for the optimization process, the technological parameters as well as the capacity constraints are defined per technological phases for the optimization process:

- recovery and depletion of the ore in the stage of excavation,
- recovery in the phase of flotation processing,
- recovery in the phase of metallurgical processing,
- limitation the open pit capacity in the phase of ore excavation,
- capacity limitation in the phase of flotation processing.
Block model is the basis of the modern open pit mine planning. The block model is a regularized, three dimensional array of blocks used to represent the properties and characteristics of the ore body. The raster representation of the ore body is beneficial to the analysis using the computerized techniques and has resulted in development a variety of algorithms and software packages that use a discretization of the ore body into a block model as their basis [2].

Figure 1 shows the zone of future exploitation in the deposit Cerovo Primarno-Drenova, with the disposition of the existing mining facilities at the site Cerovo.

![Figure 1](image)

**Figure 1** Zone of the future exploitation on the deposit Cerovo Primarno-Drenova with a disposition of the existing mining facilities in the field Cerovo

2 TECHNOCO-ECONOMIC PARAMETERS FOR OPTIMIZATION THE OPEN PIT

The techno-economic parameters used for optimization and determining the optimal open pit boundary are shown in Table 1.

The metal prices (Cu, Au, Ag) were adopted on the basis of long-term forecast of price movements on the world metal exchanges and forecast of the World Bank.
Table 1  Techno-economic parameters for optimization the open pit

| Parameter                                      | Unit    | Value  |
|------------------------------------------------|---------|--------|
| **Base metal prices**                          |         |        |
| • Copper                                       | USD/t   | 6,000  |
| • Gold                                         | USD/kg  | 40,000 |
| • Silver                                       | USD/kg  | 500    |
| **Costs of ore and overburden (excavation)**   | USD/t   | 1.30   |
| **Costs of flotation ore processing**          | USD/t   | 3.40   |
| **Costs of metallurgical concentrate processing** |       |        |
| • Costs of copper production from concentrate   | USD/t Cu cathode | 670   |
| • Costs of gold refining                       | USD/kg  | 150    |
| • Costs of silver refining                     | USD/kg  | 15     |
| **Flotation recoveries**                       | %       | 85.0   |
| • Copper                                       | %       | 85.0   |
| • Gold                                         | %       | 37.0   |
| • Silver                                       | %       | 21.0   |
| **Metallurgical recoveries**                   | %       | 98.5   |
| • Copper                                       | %       | 98.5   |
| • Gold                                         | %       | 91.0   |
| • Silver                                       | %       | 85.0   |
| **Annual capacity of ore processing**          | t/year  | 6 Mt/12 Mt |
| **Discount rate**                              | %       | 10     |

The final angles of general slopes have been adopted from the existing technical documentation [3].

3 OPTIMIZATION OF THE OPEN PIT AND SELECTION THE OPTIMUM PUSHBACKS

Generating the optimum open pit limit was performed applying the software Whittle, which uses the modified Lerchs- Grossmann algorithm. In this approach, a series of the open pits of different sizes is generated, wherein each open pit has the highest undiscounted value for the considered open pit size [4, 5].

It should be kept in mind that the only criterion used in the Whittle method is to maximize the net present value of revenues due to the sale of useful mineral resources or concentrate obtained from the open pit.

According to the Whittle methodology, the optimization algorithm can be roughly divided into three steps:

- Generating the shells of the open pits,
- The best and worst scenario of excavation,
- Selection the limit boundary of the open pit on a graph of changing the optimal contour depending on the revenue factor.

The results of optimization are shown in Tables 2 and 3 (the first 50 shells of the open pits, obtained by optimization from total 85, are shown) and on a diagram of the tonnage and Net Present Value (NPV) ratio for the best and worst case, Figures 2 and 3, for Variants I and II, respectively.
The presented diagrams represent the changes of optimal contours depending on the revenue factor of the net values. Diagrams represent the net present value for each optimal contour. The best and worst curves of the net values give the upper and lower limits of the value that can be achieved in practice [6, 7].

Table 2 Results of optimization (Variant I)
### Table 3 Results of optimization (Variant II)

| Pit  | Cash flows Bestcase | Cash flows Worstcase | Ore Bestcase | Waste Bestcase | Mine Life to years |
|------|---------------------|----------------------|--------------|----------------|-------------------|
| 1a   | 9,260,682.70c       | 9,260,682.70c        | 452,404.0c   | 33,516.0c      | 0.25              |
| 2a   | 13,139,213.0d       | 13,139,213.0d        | 694,819.0d   | 133,883.0d     | 0.25              |
| 3a   | 20,278,149.0e       | 20,278,149.0e        | 1,197,439.0e | 199,234.0e     | 0.25              |
| 4a   | 32,302,488.0f       | 32,302,488.0f        | 2,172,439.0f | 495,278.0f     | 0.25              |
| 5a   | 47,829,302.0g       | 47,829,302.0g        | 3,425,000.0g | 1,124,705.0g   | 0.25              |
| 6a   | 63,543,322.0h       | 63,543,322.0h        | 4,988,398.0h | 2,102,701.0h   | 0.25              |
| 7a   | 123,618,650.0i      | 123,618,650.0i       | 10,490,013.0i| 10,348,558.0i  | 5.00              |
| 8a   | 191,132,682.0j      | 191,132,682.0j       | 18,446,085.0j| 18,412,804.0j  | 5.00              |
| 9a   | 265,672,062.0k      | 260,056,097.0k       | 29,026,360.0k| 26,233,635.0k  | 2.00              |
| 10a  | 303,256,141.0l      | 294,107,052.0l       | 35,561,756.0l| 31,326,060.0l  | 3.00              |
| 11a  | 386,126,678.0m      | 366,773,613.0m       | 50,841,475.0m| 49,928,553.0m  | 4.00              |
| 12a  | 422,512,870.0n      | 395,961,281.0n       | 58,500,079.0n| 59,841,922.0n  | 5.00              |
| 13a  | 470,097,518.0o      | 431,131,940.0o       | 70,894,017.0o| 75,767,682.0o  | 6.00              |
| 14a  | 495,685,419.0p      | 447,987,265.0p       | 77,984,086.0p| 86,573,628.0p  | 7.00              |
| 15a  | 524,882,635.0q      | 461,134,153.0q       | 87,974,044.0q| 100,624,044.0q | 7.00              |
| 16a  | 553,431,379.0r      | 476,196,011.0r       | 110,836,404.0r| 118,195,992.0r | 8.00              |
| 17a  | 589,506,009.0s      | 480,972,031.0s       | 149,118,263.0s| 142,833,919.0s | 10.00             |
| 18a  | 649,088,078.0t      | 472,548,719.0t       | 164,497,256.0t| 210,332,798.0t | 14.00             |
| 19a  | 673,856,625.0u      | 462,889,735.0u       | 189,224,306.0u| 255,475,149.0u | 16.00             |
| 20a  | 699,140,756.0v      | 438,432,030.0v       | 228,334,024.0v| 317,448,710.0v | 19.00             |
| 21a  | 706,034,438.0w      | 429,093,165.0w       | 241,151,133.0w| 338,871,350.0w | 20.00             |
| 22a  | 711,934,000.0x      | 417,256,011.0x       | 252,223,026.0x| 362,785,601.0x | 21.00             |
| 23a  | 715,931,700.0y      | 404,651,428.0y       | 264,732,835.0y| 386,944,862.0y | 22.00             |
| 24a  | 719,412,391.0z      | 390,864,825.0z       | 273,527,022.5z| 411,458,172.5z | 23.00             |
| 25a  | 720,635,765.0{      | 385,699,911.0{       | 280,185,787.0{| 420,938,695.0{   | 25.00             |
| 26a  | 733,346,773.0| | 368,444,640.0| | 291,044,150.0| | 452,197,081.0| | 24.00 |
| 27a  | 724,887,128.0| | 356,291,639.0| | 299,297,517.0| | 474,927,517.0| | 24.00 |
| 28a  | 726,171,217.0| | 343,146,734.0| | 307,879,676.0| | 498,529,020.0| | 26.00 |
| 29a  | 726,986,520.0| | 332,224,668.0| | 314,168,735.0| | 519,816,798.0| | 26.00 |
| 30a  | 727,880,927.0| | 329,885,884.0| | 325,690,691.0| | 544,242,584.0| | 26.00 |
Figure 2 NPV tonnage graph for the best and worst case – Variant I

Figure 3 NPV tonnage graph for the best and worst case – Variant II

Based on the results of optimization process:

- For Variant I, a shell of the open pit No.19 was selected, which includes 189,294,305 t of ore and 253,473,150 t of overburden.

- For Variant II, a shell of the open pit No.30 was selected, which includes 321,469,484 t of ore and 541,567,569 t of overburden.

Figures 4 and 5 show the final contours of the open pit for Variant I and Variant II.
OPTIMIZATION OF THE EXCAVATION DYNAMICS

When the final contour of the open pit is determined, it is necessary to define the order in which the blocks will be excavated inside the final contour of the open pit, or to define the excavation dynamics.

Whittle software can calculate the lifetime of the mine with the total quantities of ore and waste, content of metals, cash flows, and discounted cash flows, that is the NPV, in accordance with the given limits by the user [8].

The Milawa algorithm, incorporated in the Whittle software, was used to optimize the excavation dynamics.

The excavation dynamics was optimized in the case of balancing the excavations, with the established requirement for a constant annual capacity of flotation ore processing, according to the considerations of Variants I and Variants II.

On the basis of selected phases of the open pit development, the dynamics was generated that is used to realize the highest profit for the company for Variant I and Variant II.

The optimized excavation dynamics with the annual cash flow for Variant I and Variant II is shown in the graphs in Figures 6 and 7, respectively.
CONCLUSION

The main goal of each mining operation is to make a profit. Basically, the mining processes are complex and complicated, with many different economic, technical, environmental and other parameters that must be planned before the project gets its practical value. Due to this, the costs, prices, reserves, excavation and processing of the
ore, as well as many social aspects, are crucial for the project evaluation.

Profitability of exploitation the Cerovo Primarno - Drenova deposit was analyzed for the following annual processing capacities:

1) For capacity of 6.0 million tons annually – Variant I, and
2) For capacity of 12.0 million tons annually – Variant II.

The obtained techno-economic results are:

**I Variant I:**
- Ore quantity: 189,294,305 t
- Overburden quantity: 253,473,150 t
- NPV: 316,895,258 $
- Life time of the mine: 32 years

**II Variant II:**
- Ore quantity: 321,469,484 t
- Overburden quantity: 541,567,568 t
- NPV: 436,554,907 $
- Life time of the mine: 28 years

Based on the analysis, it can be concluded that significantly better economic results are achieved for the annual ore processing capacity of 12.0 million tons of ore - Variant II. Generated NPV is higher by 37.76%, or 119,659,649 $.

However, in deciding on the excavation capacity, apart from the economic aspect, the social aspect as well as the state interest must be taken into account.

REFERENCES

[1] Whittle User Manual, 2014, Geovia, Dessault Systems, available at [http://www.geovia.com/node/483/?W T.ae=%20Whittle%20Whitepaper%20CTA].
[2] Kržanović D., Vušović N., Ljubojev M., Selection of the Optimum Pushbacks in a Long-Term Planning Process of the Open Pit - A Condition for Maximization the Net Present Value: Case Study: The Open Pit Veliki Krivelj, Serbia, Mining Engineering, Mining and Metallurgy Institute Bor, 1-2/2018, pp. 37-44.
[3] Feasibility Study for Exploitation of Mineral Deposits "Kraški Bugaresku" and "Cerovo", Mining and Metallurgy Institute Bor, 2008
[4] J. Whittle, Open Pit Optimization, Surface Mining, 2nd Edition, Editor Bruce A. Kennedy, Society for Mining, Metallurgy, and Exploration, Inc, Littleton, Colorado, 1990, pp. 470-475;
[5] Kržanović D., Rajković R., Mikić M., The Effect of Open Pit Slope Design on Net Present Value for Long Term Planning. The 46th International October Conference on Mining and Metallurgy, Bor Lake, Serbia, 2014;
[6] Wharton C., 2000, Add Value to Your Mine Through Improved Long Term Scheduling”, Whittle North American Strategic Mine Planning Conference, Colorado, pp. 1-13.
[7] Kržanović D., Vušović N., Ljubojev M., Rajković R, Importance of Planning the Open Pits in the Conditions of Contemporary Mining - A Case Study: The Open Pit South Mining District Majdanpek, Mining Engineering, Mining and Metallurgy Institute Bor, 1-2/2017, pp. 15-22.
[8] Kržanović D., Ljubojev M., Jovanović I., Vušović N., An Analysis the Effects of Changes in Price of Metal and Operating Costs to the Profit in Exploitation the Copper Ore Deposits, A Case Study: Copper Mine Majdanpek, Serbia, Mining Engineering, Mining and Metallurgy Institute Bor, 3-4/2017, pp. 51-58.