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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 present an economic analysis of the copper ore exploitation on the Cerovo Primarno-Drenova deposit for at 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 by 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 develop

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

2 TECHNO-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) 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		
• Copper	%	85.0
• Gold	%	37.0
• Silver	%	21.0
Metallurgical recoveries		
• 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)

Pit	Cash-flow	Cash-flow	Ore	Waste	Mine-Life
	Bestcase	Worstcase	Bestcase	Bestcase	Bestcase
	\$disc	\$disc	t	t	year
1	9,227,466	9,227,466	452,404	35,816	0
2	13,066,903	13,066,903	694,819	133,863	0
3	20,086,204	20,086,204	1,197,439	199,234	0
4	31,946,480	31,946,480	2,172,439	495,228	0
5	46,351,099	46,351,099	3,425,007	1,124,705	1
6	61,123,468	61,123,468	4,888,398	2,102,701	1
7	117,985,032	116,825,082	10,490,013	10,348,358	2
8	178,515,651	173,391,252	18,446,085	18,432,804	3
9	238,678,559	225,550,581	29,026,560	26,233,636	5
10	268,398,761	249,161,379	35,561,756	31,326,060	6
11	325,631,616	290,802,758	50,841,475	49,926,553	8
12	348,812,488	303,447,349	58,800,079	59,841,902	10
13	376,513,606	313,154,101	70,894,017	75,267,682	12
14	390,178,785	314,207,717	77,964,086	86,573,628	13
15	405,423,512	311,780,208	87,974,041	100,624,047	15
16	419,543,434	302,054,308	100,836,404	118,195,992	17
17	433,432,525	281,548,744	119,118,263	142,831,919	20
18	451,660,973	230,968,841	164,437,256	210,332,798	27
19	457,220,248	201,965,432	189,294,306	253,473,149	32
20	461,564,667	162,721,027	228,334,024	317,448,710	38
21	462,588,525	150,810,330	241,151,133	338,871,350	40
22	463,288,457	137,687,721	252,525,626	362,755,601	42
23	463,850,082	124,859,193	264,732,853	386,944,862	44
24	464,231,341	112,449,210	275,372,025	411,458,177	46
25	464,357,852	108,105,937	280,185,787	420,058,695	47
26	464,607,019	92,951,797	291,044,150	452,197,081	49
27	464,740,703	83,109,788	299,297,517	474,927,517	50
28	464,846,582	72,776,395	307,879,670	498,529,020	51
29	464,914,079	64,392,420	314,168,753	519,816,798	52
30	464,963,595	55,927,317	321,469,484	541,567,569	54
31	464,977,254	54,085,099	323,998,606	550,173,943	54
32	464,945,621	17,847,297	366,926,233	679,880,261	61
33	464,949,969	16,149,495	368,957,960	687,615,412	61
34	464,953,733	6,222,044	378,990,143	726,843,152	63
35	464,955,030	2,960,718	383,045,168	741,726,584	64
36	464,954,450	52,310	386,155,988	756,633,914	64
37	464,951,337	-3,384,337	390,320,609	773,260,277	65
38	464,950,426	-5,185,777	391,812,791	779,260,101	65
39	464,944,907	-10,597,242	396,837,312	801,113,928	66
40	464,938,811	-14,278,516	400,496,108	820,924,673	67
41	464,936,880	-15,106,803	401,634,213	826,399,038	67
42	464,932,350	-17,154,222	403,590,067	837,025,698	67
43	464,922,655	-22,601,342	407,678,814	857,623,299	68
44	464,920,133	-23,418,127	408,665,172	862,470,790	68
45	464,917,126	-24,606,532	409,710,542	868,414,879	68
46	464,911,661	-26,509,630	411,244,876	879,152,030	69
47	464,901,016	-30,553,198	414,617,038	898,321,522	69
48	464,892,884	-33,858,669	417,011,273	912,440,851	70
49	464,892,854	-33,860,022	417,019,704	912,491,486	70
50	464,892,523	-33,881,642	417,120,869	912,980,981	70

Table 3 Results of optimization (Variant II)

Pit	Cash-flow	Cash-flow	Ore	Waste	Mine-Life
	Best-case	Worst-case	Best-case	Best-case	Best-case
	\$-disc	\$-disc	to	to	years
1	9,260,682	9,260,682	452,404	35,816	0
2	13,139,213	13,139,213	694,819	133,863	0
3	20,278,149	20,278,149	1,197,439	199,234	0
4	32,502,488	32,502,488	2,172,439	495,228	0
5	47,629,302	47,629,302	3,425,007	1,124,705	0
6	63,543,332	63,543,332	4,888,398	2,102,701	0
7	123,618,659	123,618,659	10,490,013	10,348,358	1
8	193,132,682	191,674,273	18,446,085	18,432,804	2
9	265,672,962	260,056,097	29,026,560	26,233,636	2
10	303,256,141	294,107,033	35,561,756	31,326,060	3
11	386,126,676	366,773,613	50,841,475	49,926,553	4
12	422,512,970	395,967,291	58,800,079	59,841,902	5
13	470,097,918	431,131,940	70,894,017	75,267,682	6
14	495,685,419	447,987,265	77,964,086	86,573,628	6
15	524,882,635	464,134,153	87,974,041	100,624,047	7
16	555,431,579	476,196,011	100,836,404	118,195,992	8
17	589,306,005	480,972,031	119,118,263	142,831,919	10
18	649,988,097	475,548,719	164,437,256	210,332,798	14
19	673,856,422	462,889,732	189,294,306	253,473,149	16
20	699,140,756	438,432,030	228,334,024	317,448,710	19
21	706,034,458	429,093,165	241,151,133	338,871,350	20
22	711,304,000	417,256,011	252,525,626	362,755,601	21
23	715,951,270	404,051,428	264,732,853	386,944,862	22
24	719,422,391	390,864,852	275,372,025	411,458,177	23
25	720,633,760	385,699,911	280,185,787	420,058,695	23
26	723,346,772	368,446,640	291,044,150	452,197,081	24
27	724,877,124	356,291,639	299,297,517	474,927,517	25
28	726,171,217	343,146,734	307,879,670	498,529,020	26
29	726,986,527	332,224,668	314,168,753	519,816,798	26
30	727,686,074	320,656,572	321,469,484	541,567,569	27
31	727,890,277	317,538,739	323,998,606	550,173,943	27
32	729,247,431	260,860,107	366,926,233	679,880,261	31
33	729,307,379	258,037,634	368,957,960	687,615,412	31
34	729,438,061	241,874,224	378,990,143	726,843,152	32
35	729,421,182	236,034,258	383,045,168	741,726,584	32
36	729,410,759	230,799,916	386,155,988	756,633,914	32
37	729,361,973	224,433,291	390,320,609	773,260,277	33
38	729,336,194	221,719,614	391,812,791	779,260,101	33
39	729,194,457	212,547,130	396,837,312	801,113,928	33
40	729,054,721	206,062,901	400,496,108	820,924,673	33
41	729,008,704	204,449,838	401,634,213	826,399,038	33
42	728,908,496	200,749,416	403,590,067	837,025,698	34
43	728,687,095	191,772,058	407,678,814	857,623,299	34
44	728,624,732	190,119,119	408,665,172	862,470,790	34
45	728,547,953	188,156,030	409,710,542	868,414,879	34
46	728,405,354	184,627,379	411,244,876	879,152,030	34
47	728,121,375	177,423,576	414,617,038	898,321,522	35
48	727,910,602	171,970,747	417,011,273	912,440,851	35
49	727,909,791	171,963,460	417,019,704	912,491,486	35
50	727,901,057	171,887,775	417,120,869	912,980,981	35

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.

Figure 4 Contour of the final open pit boundary – Variant I a) 2D view, b) 3D view

Figure 5 Contour of the final open pit boundary – Variant II a) 2D view, b) 3D view

4 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.

Figure 6 Graphic view the optimized excavation dynamics with the cash flow (Variant I)

Figure 7 Graphic view the optimized excavation dynamics with the cash flow (Variant II)

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:

i. Ore quantity	189,294,305 t
ii. Overburden quantity	253,473,150 t
iii. NPV	316,895,258 \$
iv. Life time of the mine	32 years

II Variant II:

i. Ore quantity	321,469,484 t
ii. Overburden quantity	541,567,568 t
iii. NPV	436,554,907 \$
iv. 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.

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