Daniel Kržanović*, Radmilo Rajković*, Miomir Mišić*, Milenko Ljubojević*

ANALYSIS THE POSSIBILITY OF INCREASING CAPACITY OF COPPER ORE MINING AT THE OPEN PIT SOUTH MINING DISTRICT MAJDANPEK AT 11x10⁶ TONS ANNUALLY**

Abstract

The paper analyzes the possibility of increasing capacity at the Open Pit South Mining District in terms of achieving maximum net present value. The analysis is based on the movement of discounted cash flow during exploitation period of 18 years. The modern approach of designing the open pits was used for this consideration using the software Whittle and Gemcom Gems.

The analysis showed a positive trend of discounted cash flow from the third year until the end of analyzed period in achieving the net present value in the amount of 596 252 546 $. 

Keywords: Open Pit South mining District Majdanpek, optimization of boundary of open pit, open pit development phase, net present value, software Whittle, Gemcom

INTRODUCTION

Mining works at the open pit South Mining District, which were suspended in May 2009, continued in 2012 by stripping the deposit on location Andesite finger, on the basis of designed technical solutions by the experts from the Mining and Metallurgy Institute Bor from Bor [1], [2].

In accordance with the new strategic plan of development of copper production in RTB with the annual production capacity of 80-85 000 t of ore, it is necessary to increase the capacity of ore mining and processing at the open pit South Mining District from the existing capacity of 8.5 million tons to 11 million tons annually. Among others, this is one of the prerequisites for achieving the profitable mining and processing of copper ore.

The long-term designing of the open pit and solution to the problem of optimization was achieved by modeling the problems using software. Software, which were used, Whittle and Gems, their work based on an algorithm that is applied to a three-dimensional block model of the ore body South Mining District.

Technical and economic analysis were carried out in software Whittle, while the deposit modeling and design of optimal contour of the open pit and development phase of the open pit development were carried out in software Gemcom Gems.

* Mining and Metallurgy Institute Bor, e-mail: daniel.krzanovic@irmbor.co.rs
** This work is the result of the Project 33021 “Investigation and Monitoring the Changes of Stress-strain State in the Rock Mass “In-situ” around the Underground Rooms with Development a Model with Special Reference on the Tunnel of the Krivelj River and Jama Bor”, funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.
PROBLEMS OF THE PRODUCTION SYSTEM AT THE OPEN PIT

The basic problem of the production system at the open pit South Mining District is:

- Deviation from designed calendar plan of excavation.
- Implementation of works out of designed boundaries of the open pit.
- Delay in revitalization and rehabilitation of mining machines and infrastructure facilities (transport system for overburden TS-1 crushing plant for ore).
- Pumping of mine water, which is of crucial importance for ore mining at the open pit, has not yet commenced. Also a problem is in defining an optimal technology for treatment of such waters, as well as the treatment plant.

Also, in the coming period it is necessary to carry out the relocation of capital infrastructural facilities in the coming period, as follows:

- A route of the state road M22 I B order.
- A part of the route of the existing power line 35 kV.
- The riverbed of the river Mali Pek.
- The town collector of waste water.

METHODOLOGY

Analysis of the possibility of increasing the capacity of mining was carried out on the basis of long-term planning of copper ore exploitation at the open pit South Mining District.

The conducted analysis in this paper, with the aim of maximizing the net present value is achieved by application the method of geostatistical modeling, method of long-term planning and optimization method for open pits.

The procedure is carried out through the following steps:

1) The first step presents a development of block model using the statistical methods for analysis and assessment. Deposit modeling was performed in the software Gemcom Gems.

2) The second step is optimization the final contours of the open pit. The basis for optimization is the block model. In this paper, optimization of the open pit of copper ore was carried out in the software Whittle that applied a modified Lerchs-Grossmann algorithm. Software for generating the nested pits and defining the pushbacks uses a technique of parameterization (Revenue Factors), and calculation is based on undiscounted cash values.

3) The third step is to define the development phases of the open pit. The main reason for planning the development phase of the open pit is of economic nature, i.e. maximization the net present value.

In defining the development phases of the open pit, the following requirements are satisfied [3]:

- There is a minimum allowable distance between the phase boundaries.
- There is a minimum working width of each phase bottom.
- NPV of each phase is positive.
- NPV for defined phases is maximum.

In addition to the economic, the practical importance of the phase open pit development is also considered, and it is applied to the problems caused by the excessive number of phases which can lead to [3]:

- increase in costs for maintenance of many sites,
增加开发运输路线的成本，
- 工作平台宽度不足，不适合机械化作业，
- 增加了主辅设备的数量等。

4) 第四步定义采矿动态。分析基于Milawa算法，该算法由软件Whittle支持，且专为定义长期采矿规划策略而设计。

模型化矿床

地质储量

南采矿区南矿带的铜矿床地质储量计算使用了小块体方法，块体尺寸为15×15×15 m。计算地质储量的基础是Gemcom软件中形成的数字块体模型，该模型使用了地质统计分析和评估方法[4]，[5]。

图1显示了在南矿带南矿体的块体模型的三维视图。

图1 三维视图的块体模型Cu在南矿带

优化露天矿边界

优化过程是在定义金属销售价格、折现率和开采、浮选和冶金处理成本效率的基础上进行的。

表1列出了定义最优边界和确定开采阶段的起始参数。

Table 1 presents the starting parameters used to define the optimal contour of the open pit and defining the excavation phases.
Table 1 Starting parameters for optimization the open pit boundary and defining the excavation phases

| Parameter                                                                 | Unit     | Value   |
|---------------------------------------------------------------------------|----------|---------|
| Base metal prices                                                         |          |         |
| – Copper                                                                  | USD/t    | 6 000.00|
| – Gold                                                                    | USD/kg   | 35 000.00|
| – Silver                                                                  | USD/kg   | 650.00  |
| Costs of ore mining                                                       | USD/t    | 1.50    |
| Costs of overburden mining                                                | USD/t    | 2.50    |
| Costs of flotation ore processing                                         | USD/t    | 3.20    |
| Costs of metallurgical treatment of concentrate                           |          |         |
| – Costs of copper production from concentrates                           | USD/t Cu cathode | 600.00 |
| – Costs of gold refining                                                  | USD/kg   | 150.00  |
| – Costs of silver refining                                                | USD/kg   | 15.00   |
| Flotation copper recovery from ore                                        | %        | 86.0    |
| Metallurgical copper recovery from ore                                     | %        | 98.5    |
| Total recovery on gold                                                    | %        | 50.0    |
| Total recovery on silver                                                  | %        | 50.0    |
| Discount rate                                                             | %        | 10      |

Ore mining capacities are limited by years, based on assessment the possibility of increasing the capacity of flotation processing.

The planned value of ore mining capacity at annual level is as follows:

1. In the 1st and 2nd year

   - 6 000 000 t of ore

2. In the 3rd year

   - 8 500 000 t of ore

   ➢ in the 4th year to the end of the exploitation period

   - 11 000 000 t of ore

Overburden mining is limited by the capacity of the transport system for waste TS-1 (27 million tons per year) and capacity of the external waste dumps (Table 2 and Figure 2). Due to this reason, maximum designed capacity of waste is 32 million tons per year.

Table 2 View the capacities of the external waste dumps

| Capacities of the outer waste dumps | Total     |
|-------------------------------------|-----------|
| Kovej                               | 1 995 000 |
| Andesite finger                     | 8 000 000 |
| Bugarski potok                     | 13 000 000|
| Dump                               | 23 500 000|
|                                     | **46 495 000** |
The optimum boundary of excavation the open pit was obtained using the software for optimization and strategic planning of the open pits Whittle [6], [7]. Figure 3 graphically shows the results of optimization for the base copper price of 6000 USD/t, on the basis of which the optimal contour of the open pit and development phases of the open pit are selected.

---

**Figure 2** View of the truck dumps

**Figure 3** Graphical presentation of optimization results (Pit by pit graph)
It can be seen from graph that, for the adopted technical-economic parameters the open pit No. 25 was chosen as the optimal one. The selected open pit has total of 549,837,135 t excavation, out of which 175,536,668 t of ore and 374,300,467 t of overburden. Overburden coefficient is 2.13 t/t.

**Defining the development phases of the open pit (Pushbacks)**

After determining the final borders of mining, the next step in the process of designing the open pits is to define the excavation phases.

Simulations and DCF analysis are carried out in this step to obtain the most favorable variant, or determine the number of phases that affect the maximization of net present value for long-term planning of open pits.

Based on the results of optimization, which is graphically shown in Figure 3, the excavation phases are defined and those are the open pits Nos. 18 and 22. Based on a need of providing the quantities of ore by the mining dynamics, according to the request of the Investor, with minimum quantity of overburden, it is necessary to split the open pit No. 18 into four phases, whereby the northern part is the Phase 1, the eastern phase is the Phases 2 and 3, and the southern and western part are designated as the Phase 4. Pursuant to the adopted rule of labeling the phases, the open pits Nos. 22 and 25 are defined as the Phase 5 and Phase 6, respectively (Figure 4).

![Figure 4 View of the final contour (3D view)](image)

**Optimization of mining dynamics**

Mining dynamics by years of exploitation was obtained in Whittle software. To optimize the mining dynamics, the used software was Milawa algorithm for balancing regime (Milawa Balanced) [8].

Results of optimization the mining dynamics are shown in Table 3.
Table 3 Mining dynamics by years and periods of exploitation

| Year | Ore (t) | Overburden (t) | Excavation (t) | Overburden coefficient (t/t) | Cu % | Ag g/t | Au g/t | Cash flow $ | Cash flow (disc) $ |
|------|---------|----------------|----------------|-----------------------------|------|-------|-------|-------------|-----------------|
| 1    | 5,999,814 | 32,000,116 | 38,000,000 | 5.33 | 0.255 | 1.220 | 0.159 | -22,398,758 | -20,362,567 |
| 2    | 6,000,000 | 24,936,051 | 30,936,051 | 4.16 | 0.275 | 0.910 | 0.092 | -19,029,178 | -9,322,379 |
| 3    | 8,498,390 | 31,501,110 | 40,000,000 | 3.71 | 0.332 | 0.980 | 0.150 | 19,911,446 | 14,973,700 |
| 4    | 10,999,696 | 29,000,304 | 40,000,000 | 2.64 | 0.371 | 1.441 | 0.310 | 109,734,414 | 74,959,081 |
| 5    | 11,000,000 | 25,307,661 | 36,307,661 | 2.30 | 0.340 | 1.197 | 0.188 | 82,744,790 | 51,378,004 |
| 6    | 10,998,579 | 32,001,421 | 43,000,000 | 2.91 | 0.372 | 1.065 | 0.211 | 88,765,834 | 50,105,999 |
| 7    | 10,993,690 | 32,006,310 | 43,000,000 | 2.91 | 0.396 | 2.292 | 0.288 | 110,481,287 | 56,694,369 |
| 8    | 10,999,785 | 32,000,215 | 43,000,000 | 2.91 | 0.393 | 2.042 | 0.301 | 112,074,145 | 52,283,416 |
| 9    | 10,987,165 | 32,012,834 | 42,999,999 | 2.91 | 0.404 | 1.587 | 0.265 | 113,388,664 | 48,086,057 |
| 10   | 10,999,999 | 27,167,299 | 38,167,298 | 2.47 | 0.430 | 1.319 | 0.211 | 118,184,201 | 45,565,126 |
| 11   | 10,999,999 | 21,171,797 | 32,171,796 | 1.92 | 0.412 | 1.244 | 0.187 | 143,817,710 | 50,467,230 |
| 12   | 10,999,996 | 24,875,159 | 35,875,158 | 2.26 | 0.404 | 0.888 | 0.110 | 95,904,893 | 30,558,255 |
| 13   | 11,000,000 | 25,766,972 | 36,766,972 | 2.34 | 0.344 | 1.939 | 0.170 | 74,240,820 | 21,504,921 |
| 14   | 11,000,000 | 8,467,334 | 19,467,334 | 0.77 | 0.334 | 2.192 | 0.220 | 124,017,674 | 32,657,730 |
| 15   | 11,000,000 | 3,536,252 | 14,536,252 | 0.33 | 0.337 | 2.022 | 0.189 | 132,320,385 | 31,676,448 |
| 16   | 10,999,988 | 9,514,114 | 11,009,512 | 0.00 | 0.329 | 2.189 | 0.165 | 123,997,165 | 28,944,058 |
| 17   | 10,999,986 | 0    | 10,999,986 | 0.341 | 1.303 | 0.159 | 137,458,664 | 27,955,464 |
| 18   | 4,288,324 | 0    | 4,288,324 | 0.320 | 1.068 | 0.122 | 45,559,243 | 8,684,884 |
| Total | 178,766,084 | 381,760,349 | 560,526,353 | 2.14 | 0.241 | 1.193 | 0.201 | 1,608,243,399 | 596,252,546 |

CONCLUSION

The performed analysis the possibilities for increasing the capacity at the open pit South Mining District was carried out using the software for optimization and strategic planning of the open pits Whittle, which is based on an analysis of trends the discounted cash flow during its service period, or the net present value, and that is an indicator of the achieved economic results of exploitation the deposit South Mining District for the given initial conditions. Deposit modeling and design of optimal contour of the open pit and the phases of development the open pit are carried out in the software Gemcom Gems.

On the basis of performed analysis, the following is concluded:

1) There is a possibility to increase the capacities of copper ore excavation at the open pit South Mining District Majdanpek, which is realized in the 4th year for the analyzed period.

2) Service life of the open pit mining is 18 years.

3) Movement in cash flow is positive throughout the whole period of exploitation, except in the first and second year of the analyzed period.

4) The net present value is achieved in the amount of 596,252,546 $.

REFERENCES

[1] D. Kržanović et al., Feasibility Study on Mining the South Mining District Deposit in the Copper Mine Majdanpek (MMI Bor, 2011.), (in Serbian)

[2] D. Kržanović et al. Additional Mining Design of Copper Ore Mining from the South Mining District Deposit in the Copper Mine Majdanpek (MMI Bor), (in Serbian)
[3] D. Kržanović, R. Rajković, M. Mikić, M. Ljubojev: Effect of Stage Development of Mining Operations on Maximization the Net Present Value in Long-Term Planning of Open Pits, Mining and Metallurgy Engineering Bor, 4/2014, pp. 33-40;

[4] D. Kržanović, M. Žikić, R. Pantović: Important Improvement of Utilization the Available Geological Reserves of the South Mining District Deposit in Majdanpek in the New Defined Optimum Contour of the Open Pit Using the Whittle and Gemcom Software, Mining Engineering, Mining and Metallurgy Institute Bor, 2012, pp. 29-36

[5] D. Kržanović, M. Žikić, Z. Vaduvesković: Innovated Block Model of the Copper Ore Deposit South Mining District-Majdanpek As a Basis for Analysis the Optimum Development of Open Pit Using the Software Packages Whittle and Gemcom, Mining Engineering, Mining and Metallurgy Institute Bor, 2011, pp 69-76

[6] G. Whittle, W. Stange and N. Hanson, Optimising Project Value and Robustness, Project Evaluation Conference, Melbourne, Vic, 19 - 20 June 2007, pp. 1-10;

[7] D. Kržanović, R. Rajković, M. Mikić: 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;

[8] D. Kržanović, R. Rajković, M. Mikić, M. Ljubojev: Effect of Stage Development of Mining Operations on Maximization the Net Present Value in Long-Term Planning of Open Pits.
ANALIZA MOGUĆNOSTI POVEĆANJA KAPACITETA OTKOPAVANJA RUDE BAKRA NA POVRŠINSKOM KOPU JUŽNI REVIR MAJDANPEK NA 11x10⁶ TONA GODIŠNJE**

Izvodi

U radu je izvršena analiza mogućnosti povećanja kapaciteta na površinskom kopu Južni revir sa aspekta ostvarivanja maksimizacije neto sadašnje vrednosti. Analiza se bazira na kretanju diskontovanog novčanog toka tokom eksploatacionog perioda od 18 godina. Za ovo sagledavanje korišćen je savremeni pristup projektovanju površinskih kopa primenom softvera Whittle i Gemcom Gems.

Analiza je pokazala pozitivno kretanje diskontovanog novčanog toka od treće godine do kraja analiziranog perioda, pri čemu se ostvaruje neto sadašnja vrednost u iznosu od 596.252.546 $. Ključne reči: površinski kop Južni revir Maidanpek, optimizacija granice kopa, fazni razvoj kopa, neto sadašnja vrednost, softver Whittle, softver Gemcom Gems

UVOD

Rudarski radovi na površinskom kopu Južni revir, koji su obustavljeni maja 2009. godine, nastavljeni su 2012. godine, raskrivanjem ležišta na lokaciji Andezitskog prsta, na osnovu projektovanih tehničkih rešenja od starne stručnjaka iz Instituta za rudarstvo i metalurgiju Bor iz Bora [1], [2].

U skladu sa novim strateškim planom razvoja proizvodnje bakra u RTB-u sa godišnjim kapašitetom proizvodnje od 80-85.000 t rude, neophodno je povećanje i kapaciteta otkopavanja i prerade rude na površinskom kopu Južni revir sa postojećeg kapaciteta od 8,5 miliona tona na 11 miliona tona na godišnjem nivou. Pored ostalih, ovo je jedan od preduzlova za ostvarivanje profitabilne eksploatacije i prerade rude bakra.

Dugoročno projektovanje površinskog kopa i rešenje problema optimizacije ostvareno je modeliranjem problema primenom softvera. Softveri koji su korišćeni, Whittle i Gems, svoj rad baziraju na algoritmu koji se primenjuje na trodimenzionalnom bloku modela rudnog tela Južni revir.

Tehničko-ekonomska analiza izvršena je u softveru Whittle, dok je modeliranje ležišta i konstrukcija optimalne konture kopa i faza razvoja kopa izvršena u softveru Gemcom Gems.

Daniel Kržanović* Radmilo Rajković*, Miomir Mikić*, Milenko Ljubojev*
PROBLEMATIKA PROIZVODNOG SISTEMA NA KOPU

Osnovna problematika proizvodnog sistema na površinskom kopu Južni revir jeste:

- Odstupanje od projektovanog kalendarskog plana otkopavanja.
- Izvođenje radova van projektovanih granica kopa.
- Kašnjenje u revitalizaciji i sanaciji rudarskih mašina i infrastrukturnih objekata (transportni sistem za jalovinu TS-1, drobilično postrojenje za rudu).
- Ispumpavanje rudničkih voda, što je od presudnog značaja za otkopavanje rude na kopeno, nije započeto. Problem je i definisanje optimalne tehnologije prečišćavanja tih voda, kao i samog postrojenja za prečišćavanje.

Takođe, u narednom periodu neophodno je da se izvrši izmeštanje kapitalnih infrastrukturnih objekata i to:

- trase državnog puta M22 I B reda,
- dela trase postojećeg dalekovoda 35 kV,
- korita reke Mali Pek,
- gradskog kolektora otpadnih voda.

METODOLOGIJA

Analiza mogućnosti povećanja kapaciteta otkopavanja sprovedena je na osnovu dugoročnog planiranja eksploatacije rude bakra na površinskom kopu Južni revir.

Sprovedena analiza u ovom radu sa ciljem postizanja maksimalne neto sadašnje vrednosti, ostvarena je primenom metoda geostatističkog modeliranja, metoda dugoročnog planiranja i metoda optimizacije površinskih kopova.

Procedura je sprovedena je kroz sledeće korake:

1. Prvi korak predstavlja izradu blok modela primenom geostatističkih metoda za analizu i procenu. Modeliranje ležišta izvršeno je u softveru Gemcom Gems.
2. Drugi korak je optimizacija završne konture površinskog kopa. Osnova za optimizaciju jeste blok model. U ovom radu optimizacija površinskog kopa rude bakra izvršena je u softveru Whittle, koji primenjuje modifikovani Lerchs-Grossmann algoritam. Softver za generisanje ugnježdenih kopa i definisanje pushback-ova koristi tehniku parametrizacije (Revenue Factors), a proračun se zasniva na nediskontovanim novčanim vrednostima.
3. Treći korak je definisanje faze razvoja površinskog kopa. Osnovni razlog za planiranje faznog razvoja kopa jeste ekonomske prirode, odnosno maksimizacija neto sadašnje vrednosti.

Kod definisanje faze razvoja kopa zadovoljeni su sledeći zahtevi [3]:

- postoji minimalno dozvoljeno rastojanje između granica faze,
- postoji minimalna radna širina dna svake faze,
- NPV svake faze je pozitivna,
- NPV za definisane faze je maksimalna.

Pored ekonomskog, uvažen je i praktičan značaj faznog razvoja kopa, a odnosi se na problematiku uzrokovana prevelikim brojem faza što može da dovede do [3]:

- povećanja troškova zbog održavanja više radilišta,
- povećanja troškova zbog ponovne izrade transportnih puteva,
nedovoljne širine radnih platoa za rad mehanizacije,
povećanog broj osnovne i pomoćne opreme i dr.

4) Četvrti korak predstavlja definisanje dinamike otkopavanja. Analiza se bazira na Milawa algoritmu, koji podržava softver Whittle, a specifično je namenjen za definisanje dinamike otkopavanja kod strategije dugoročnog planiranja eksploatacije.

**Modelovanje ležišta**

Geološke rezerve ležište bakra Južni revir Majdanpek sračunate su metodom mini blokova, pri čemu su dimenzije blokova 15x15x15 m. Osnova za proračun geoloških rezervi jeste digitalni blok model ležišta koji je formiran u softveru Gemcom, primenom geostatističkih metoda analize i procene [4], [5].

Na slici 1 prikazan je trodimenzionalni izgled blok modela Cu u ležištu Južni revir.

![Sl. 1. Trodimenzionalni izgled blok modela Cu u ležištu Južni revir](image)

**Optimizacija granice površinskog kopa**

Proces optimizacije sproveden je na osnovu definisane prodajne cene metala, diskontne stope i troškova i iskorišćenja otkopavanja, flotacijske i metalurške prerade.

U tabeli 1 dati polazni parametri koji su poslužili za definisanje optimalne konfiguracije kopa i definisanje faza otkopavanja.
**Табела 1. Полазни параметри за оптимизацију граница копа и дефинисање фаза откопавања**

| Параметар | Единица | Вредност  |
|-----------|---------|-----------|
| Базне цени метала | | |
| – Брака | USD/t | 6 000,00 |
| – Злато | USD/kg | 35 000,00 |
| – Сребро | USD/kg | 650,00 |
| Трошкови откопавања руде | USD/t | 1,50 |
| Трошкови откопавања жаловине | USD/t | 2,50 |
| Трошкови флотацијске прерађе руде | USD/t | 3,20 |
| Трошкови металуршки прерађе концентрати | | |
| – Трошкови производње брака из концентрата | USD/т Cu катоде | 600,00 |
| – Трошкови рафинације злато | USD/kg | 150,00 |
| – Трошкови рафинације сребра | USD/kg | 15,00 |
| Флотацијско искоришћење брака из руде | % | 86,0 |
| Металуршки искоришћење брака из руде | % | 98,5 |
| Укупно искоришћење на злату | % | 50,0 |
| Укупно искоришћење на сребру | % | 50,0 |
| Дисконтна стопа | % | 10 |

Капацитети откопавања руде лимитиране су по годинама, на основу процене могућности пoveћања капацитета флотацијске прерађе.

Планирана вредност капацитета откопавања руде на годишњем нивоу следећа:
- у 1. и 2. години: 6.000.000 т руде
- у 3. години: 8.500.000 т руде
- у 4. години до краја експлоатационог периода: 11.000.000 т руде

Откопавање жаловине ограничена је капацитетом транспортног система за жаловину TS-1 (27 милиона тона годишње) и капацитетом спољашњих одалагалишта жаловине (табела 2 и слика 2). Из тог разлога максимални пројектовани капацитет жаловине изнosi 32 милиона тона годишње.

**Табела 2. Пrikaz kapaciteta spoljašnjih odlagalista jalovine**

| Kapaciteti spoljašnjih odlagalista jalovine | Ukupno |
|------------------------------------------|--------|
| Ковеј | Андезитски прст | Бугарски поток | Деponija |
| 1 995 000 | 8 000 000 | 13 000 000 | 23 500 000 | 46 495 000 |
Optimalna granica otkopavanja površinskog kopa dobijena je korišćenjem softvera za optimizaciju i strateško planiranje površinskih kopova Whittle [6], [7]. Na slici 3 grafički su prikazani rezultati optimizacije za baznu cenu bakra od 6 000 USD/t, na osnovu čega se vrši izbor optimalne konture kopa i faze razvoja kopa.
Sa grafika može se videti da je, za usvojene tehno-ekonomiske parametre kao optimalan izabran kop broj 25. Izabran kop ima ukupno 549.837 t iskopina, od čega 175.536.668 t rude i 374.300.467 t otkrivke. Koeficijent otkrivke iznosi 2,13 t/t.

**Definisanje faza razvoja kopa (pushbacks)**

Nakon određivanja konačne granice otkopavanja, sledeći korak u procesu dizajniranja površinskih kopava jeste definisanje faza otkopavanja.

U ovom koraku sprovodi se simulacija i DCF analiza da bi se dobila najpovoljnija varijanta, odnosno odredio broj faza koji utiče na maksimizaciju neto sadašnje vrednosti kod dugoročnog planiranja kopova. Na osnovu rezultata optimizacije koja je grafički prikazana na slici 3, definisane su i faze otkopavanja i to su kopovi 18 i 22. Na osnovu potrebe da se dinamikom otkopavanja obezbede potrebne količine rude shodno zahtevu Investitora, uz minimalne količine otkrivke neophodno je da se i kop broj 18 podeli na četiri faze, pri čemu njegov severni deo predstavlja Fazu 1, istočni Fazu 2 i 3, a južni i zapadni deo su označeni kao Faza 4. Shodno usvojenom pravilu označavanja faza, kopovi 22 i 25 definisani su kao Faza 5 i Faza 6, respektivno (slika 4).

**Optimizacija dinamike otkopavanja**

Dinamika otkopavanja po godinama eksploatacije dobijena je u softveru Whittle. Za optimizaciju dinamike otkopavanja softver korišćen je Milava algoritam, za režim balansiranja (Milawa Balanced) [8]. Rezultati optimizacije dinamike otkopavanja prikazani su u tabeli 3.
Tabela 3. Dinamika otkopavanja po godinama i periodima eksploatacije

| Godina | Ruda (t) | Otkrića (t) | Ekipne (t) | Količenost otkrivanja (t) | Cu | Ag | Au | Novčani tok (dtls) |
|--------|----------|-------------|------------|--------------------------|----|----|----|-------------------|
| 1      | 5 999 854 | 32 000 116  | 38 000 000 | 3,33                      | 0,253 | 1,230 | 0,159 | -22 398 758       |
| 2      | 6 000 000  | 24 936 051  | 30 936 051 | 4,16                      | 0,275 | 0,910 | 0,092 | -10 929 178       |
| 3      | 4 408 890  | 31 501 110  | 40 000 000 | 3,71                      | 0,332 | 0,980 | 0,150 | 19 931 446        |
| 4      | 10 999 999 | 29 000 304  | 40 000 000 | 2,64                      | 0,371 | 1,441 | 0,310 | 109 734 414       |
| 5      | 11 000 000 | 25 207 661  | 36 207 661 | 2,03                      | 0,349 | 1,197 | 0,188 | 62 744 790        |
| 6      | 10 999 999 | 32 000 421  | 43 000 000 | 2,91                      | 0,372 | 1,065 | 0,211 | 88 765 854        |
| 7      | 10 999 999 | 32 000 215  | 43 000 000 | 2,91                      | 0,393 | 2,642 | 0,301 | 112 074 145       |
| 8      | 10 997 165  | 32 012 834  | 42 999 999 | 2,91                      | 0,404 | 1,587 | 0,265 | 133 338 644       |
| 9      | 10 999 999 | 37 167 599  | 38 167 998 | 2,47                      | 0,430 | 1,319 | 0,211 | 118 184 291       |
| 10     | 10 999 999 | 21 171 797  | 32 171 796 | 1,92                      | 0,412 | 1,244 | 0,187 | 143 817 710       |
| 11     | 10 999 999 | 24 875 159  | 35 875 158 | 2,26                      | 0,404 | 0,888 | 0,110 | 95 904 893        |
| 12     | 10 999 999 | 25 766 972  | 36 766 972 | 2,34                      | 0,344 | 1,939 | 0,170 | 74 240 820        |
| 13     | 10 999 999 | 8 467 334   | 19 467 334 | 0,77                      | 0,334 | 2,192 | 0,220 | 124 017 674       |
| 14     | 10 999 999 | 3 536 252   | 14 536 252 | 0,32                      | 0,337 | 2,022 | 0,189 | 132 320 385       |
| 15     | 10 999 999 | 9 514       | 11 009 512 | 0,00                      | 0,329 | 1,389 | 0,165 | 132 997 165       |
| 16     | 10 999 999 | 0           | 10 999 999 | 0,341                     | 1,203 | 0,159 | 0,159 | 137 458 664       |
| 17     | 10 999 996 | 0           | 4 288 324  | 0,320                     | 1,068 | 0,122 | 0,224 | 45 593 263        |
| 18     | 4 288 324  | 0           | 4 288 324  | 0,320                     | 1,068 | 0,122 | 0,224 | 8 684 884         |
| Ukupno | 178 766 004 | 381 760 249 | 560 526 353 | 2,14                     | 0,361 | 1,493 | 0,201 | 1 608 243 399     | 596 252 546 |

ZAKLJUČAK

Sprovedena analiza mogućnosti povećanja kapaciteta na kopu Južni revir obavljena je korišćenjem softvera za optimizaciju i strateško planiranje površinskih kopova Whittle, a koja se zasniva na analizi kretanja diskontovanog novčanog toka tokom eksploatacionog perioda, odnosno ostvarene neto sadašnje vrednosti, i koja je pokazatelj postignutih ekonomskih rezultata eksploatacije ležišta Južni revir za zadate početne uslove. Modeliranje ležišta i konstrukcija optimalne konture kopa i faza razvoja kopa izvršena je u softveru Gemcom Gems.

Na osnovu sprovede analize zaključuje se sledeće:

1) Postoji mogućnost povećanja kapaciteta na otkopavanju rude bakra na površinskom kopu Južni revir Majdanpek, koji se ostvaruje u 4. godini za analiziran period

2) Vek eksploatacije kopa iznosi 18 godina.

3) Kretanje novčanog toka je pozitivno tokom celog perioda eksploatacije, sem u prvoj i drugoj godini analiziranog perioda.

4) Ostvaruje se neto sadašnja vrednost u iznosu od 596.252.546 $.

LITERATURA

[1] D. Kružanović i drugi, Studija izvodljivosti eksploatacije ležišta Južni revir u Rudniku bakra Majdanpek (IRM Bor, 2011. godina)
[2] D. Kružanović i drugi, Dopunski rudarski projekat otkopavanja rude bakra iz ležišta Južni revir u Rudniku bakra Majdanpek (IRM Bor)
[3] D. Kružanović, R. Rajković, M. Mikić, M. Ljubojev: Effect of stage develop-
ment of mining operations on maximization the net present value in long-term planning of open pits, Mining and Metallurgy Engineering Bor, 4/2014, pp. 33-40.

[4] D. Kržanović, M. Žikić, R. Pantović: Important improvement of utilization the available geological reserves of the South mining district deposit in Majdanpek in the new defined optimum contour of the open pit using the Whittle and Gemcom softwares, Rudarski radovi – Mining Engineering, Institut za rudarstvo i metalurgiju Bor, 2012, pp 29-36.

[5] D. Kržanović, M. Žikić, Z. Vadaykovskić: Innovated block model of the copper ore deposit South mining district-Majdanpek as a basis for analysis the optimum development of open pit using the software packages Whittle and Gemcom, Rudarski radovi – Mining Engineering, Institut za rudarstvo i metalurgiju Bor, 2011, pp 69-76.

[6] G Whittle, W Stange and N Hanson, Optimising Project Value and Robustness, Project Evaluation Conference, Melbourne, Vic, 19 - 20 June 2007, pp. 1-10.

[7] D. Kržanović, R. Rajković, M. Mikić: The effect of open pit slope design on net present value for long term planning, The 46th International October Conference on Mining and Metallurgy, Borsko jezero, Serbia, 2014.

[8] D. Kržanović, R. Rajković, M. Mikić, M. Ljubojev: Effect of stage development of mining operations on maximization the net present value in long-term planning of open pits.