The 56th International October Conference on Mining and Metallurgy
22-25 October 2025, Bor Lake, Bor, Serbia
www.ioc.tfbor.bg.ac.rs

DOI: 10.5937/IOC25090K Original scientific paper

NPV BASED OPTIMIZATION OF FINAL PIT CONTOURS IN THE CEMENTACIJA MINING COMPLEX

Daniel Kržanović[1a], Milenko Jovanović[1b], Radmilo Rajković[1c], Miljan Gomilanović[1d], Miloš Stojanović[1e]

[1] Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia
[1a] daniel.krzanovic@irmbor.co.rs, 0000-0003-3841-8667
[1b] milenko.jovanovic@irmbor.co.rs, 0000-0002-6757-4143
[1c] radmilo.rajkovic@irmbor.co.rs, 0000-0001-5905-6613
[1d] miljan.gomilanovic@irmbor.co.rs, 0000-0002-1209-7423
[1e] milos.stojanovic@irmbor.co.rs, 0000-0003-0044-5491

Abstract
The final pit contour optimization for the Cementacija 2 and Cementacija 3 open pit was carried out using Whittle™ Four-X (LG 3D) algorithms. A series of pit shells was generated based on varying Revenue Factors (RF) to reflect changes in metal prices. The objective was to maximize the Net Present Value (NPV), using input parameters, such as mining capacity, slope angles, dilution, recovery rates, processing costs, and metal prices. A total of 77 pit shells were evaluated across three scenarios: Best Case, Worst Case, and Specified Case. Shell whose RF is 1 was identified as the most suitable final contour, achieving the highest NPV in the Best Case scenario (USD 117.15 million) and demonstrating strong economic performance across alternative cases. This shell also satisfies spatial constraints, making it suitable for detailed design and long-term planning.

***Keywords**: open pit optimization, NPV, Whittle, Revenue Factor, pit shell*

1. INTRODUCTION

Open pit mine design and planning are critical components of surface mining operations. Determining the final pit limit ensures that ore extraction is technically feasible, economically optimized, and environmentally compliant. Optimization of the pit boundary involves the geological and operational modeling, which is realized through the application of optimization software that uses some of the mathematical algorithms. The process involves identifying the combination of controlled variables that maximize the project value in the context of a given set or range of assumptions [1].

Advances in computational algorithms have enabled the use of optimization software such as Whittle™ Four-X, which applies the Lerchs-Grossmann algorithm to determine the most profitable pit shell [2,3]. In this study, final pit contours for the Cementacija 2 and 3 deposits were optimized to maximize project value while considering site-specific constraints and economic assumptions.

2. METHODOLOGY

2.1 Input parameters

Input parameters were established based on technical studies and economic forecasts:

- Annual mining capacity: 3.5 million tons of ore.
- Final pit slope angle: 38°, reflecting geotechnical assessments.
- Dilution and recovery: 3% dilution; 96% recovery.
- Cut-off grade: 0.15% Cu.

- Processing and recovery data: Based on flotation and metallurgical recovery historical figures.
- Metal prices: Copper, gold, and silver prices defined in accordance with internal pricing models.

2.2 Block model of the Cerovo ore body

Block model of the Cementacija 2 and Cementacija 3 open pit is represented by mini-blocks with dimensions of 5.0 × 5.0 × 5.0 meters.

A block model was formed with: 600 rows, 420 columns, 180 levels.

By creating a block model, the following values were defined for each block: type of rock, volumetric mass, content of useful and harmful components Cu (%), Au (g/t), Ag (g/t), S (%), Cuox (%), Cus (%) and the economic value of the block, i.e. the amount of copper in the block or profit, which is realized by mining that block.

2.3 Optimization process

Using Whittle™ Four-X (LG 3D), 77 pit shells were generated across a Revenue Factor range of 0.3 to 2.0 in steps of 0.02 [2]. For each shell, technical (ore, waste, grades) and economic (NPV) indicators were calculated [4]. The analysis involved three scenarios:

- Best Case: Assumes ideal operational angles and sequential shell mining.
- Worst Case: Reflects conservative bench-by-bench mining with minimal slope angles.
- Specified Case: Combines selected shells (7, 12, 14, 18, 36) chosen via the automated NPV pushback tool.

NPV calculations used an 8% discount rate and considered direct operational costs. Capital costs, land acquisitions, and legal compensations were excluded at this stage.

3. RESULTS AND DISCUSSION

The analysis of discounted cash flows was performed with the aim of determining the final contour of the Open Pit Cementacija 2 and Cementacija 3. During the optimization, the base price of metal was varied in the Revenue Factor range from 0.30 to 2.00 with a step of 0.02, and in this way the 77 potential surface open pit contours were generated. The amounts of waste, ore and metal are determined for each open pit contour individually with the operational NPV discounted by 10%.

Figure 1 shows the Pit by pit graph with the economic optimization parameters.

Each generated pit shell provided insight into reserve tonnage, waste volume, metal grades, and financial return. Notable findings include:

- **Shell 36 (RF 1.00)**: Highest Best Case NPV (USD 117.15 million), and favorable results in the Specified (USD 110.33 million) and Worst Case (USD 79.37 million).
- **Shell 30 (RF 0.88)**: Top Specified Case NPV (USD 111.62 million), but lower Best/Worst Case values.

Shell 36 was chosen as optimal due to a combination of maximum reserve utilization and spatial compatibility with field constraints:

- **West**: Bor-Majdanpek railway.
- **South**: Water reservoir and administrative facilities.
- **East**: Cerova River.
- **North**: License boundary.

Although full operational and capital cost data were not included, results provide a preliminary framework for pit design. Future optimization will refine phase development (pushbacks), year-by-year production schedules, and full economic models [2,5].

The parameters of the optimal open pit contour are listed in Table 1.

Table 1. Techno-economic parameters of the optimal open pit

Parameter	Unit	Value
Ore	ton	23,641,304
Waste	ton	53,684,070
Stripping ratio	t/t	2.27
Average copper grade	%	0.250
Average gold grade	g/t	0.100
Average silver grade	g/t	1.300

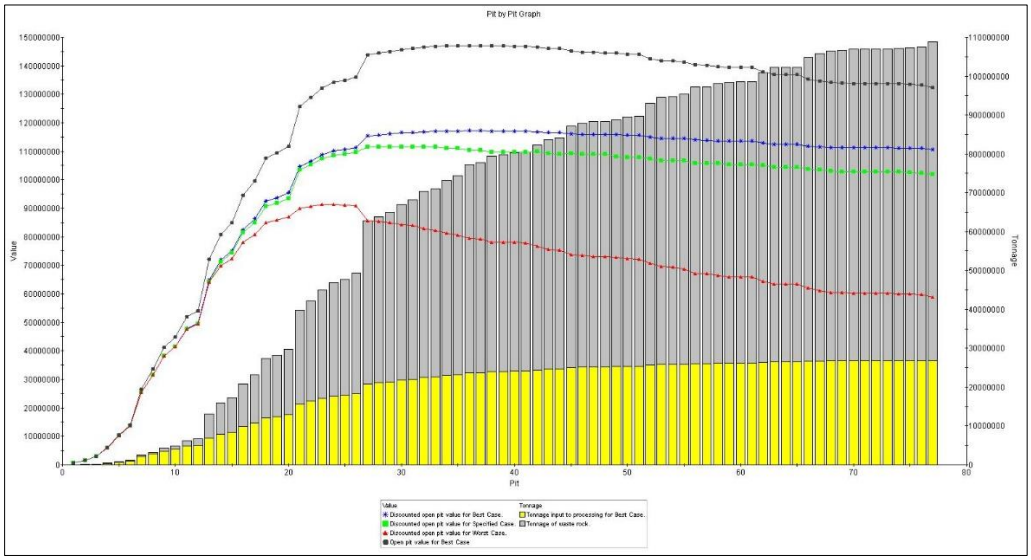

Figure 1. Pit by pit graph

A graphic representation of the Whittle shell of the final contour of pit number 36 is given in Figure 2.

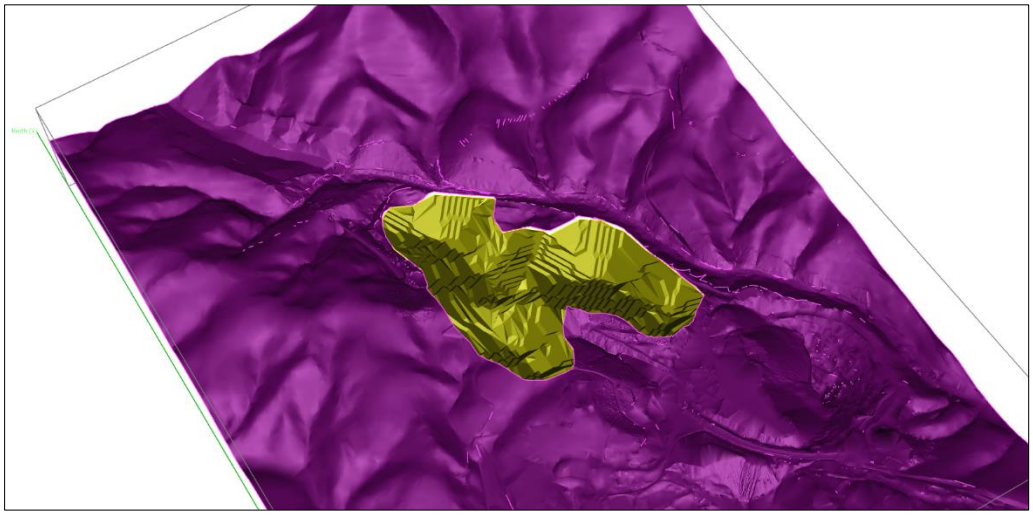

Figure 2. Whittle 3D view of the optimal pit number 36

4. CONCLUSION

The optimization of the final pit contour for the Cementacija 2 and 3 open pits, conducted using the Whittle™ Four-X (LG 3D) algorithm, successfully identified the most economically viable pit shell based on Net Present Value (NPV) analysis. By evaluating 77 pit shells under varying revenue factors and three development scenarios (Best, Worst, and Specified Case), shell 36 (RF 1.00) was determined to offer the highest economic potential while also respecting the spatial and environmental constraints of the site. Although the input parameters used are preliminary and exclude certain capital and operating costs, the results provide a reliable foundation for further detailed design, phase planning, and economic assessment of the project. The chosen contour ensures the exploitation of maximum ore reserves with a favorable project lifespan, supporting strategic decision-making for future mine development and investment planning.

ACKNOWLEDGEMENTS

This work was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract on realization and financing of the scientific research work of the Mining and Metallurgy Institute Bor in 2025, contract number: 451-03-136/2025-03/ 200052.

REFERENCES

[1] Daniel Kržanović, Radmilo Rajković, Ivana Jovanović, Milenko Jovanović, Miomir Mikić, Determination the final contour of the open pit Veliki Krivelj for the mining capacity 23.1 million tons of ore, The 54th International October Conference on Mining and Metallurgy, 18-21 October 2023, Bor Lake, Serbia, Proceedings, pp. 132-135.
[2] Whittle Consulting. Whittle Four-X User Manual (2021).
[3] Lerchs, H., & Grossmann, I. F.. Canadian Mining and Metallurgical Bulletin (1965).
[4] D. Kržanović, M. Ljubojev, I. Jovanović, N. Vušović, 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 & Metallurgy Engineering Bor, No. 3-4 2017, pp. 51-58.
[5] Hustrulid, W., Kuchta, M., & Martin, R. K. CRC Press (2013).