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# Strategic planning of open pit mining operations using the Micromine Beyond Optimiser

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**Abstract.** Modern software products allow to determine the quantity and quality of ore at any point of the deposit and, accordingly, to identify the optimal pit shell using specialized algorithms. Such algorithms make it possible to create the final open pit shell even with a broken bottom for several neighboring ore bodies. Currently, optimization solutions in the mining industry require the determination of the maximum present value of profit or the minimum stated costs. It allows to make strategic planning decisions. Strategic planning of open-pit mining operations in the development of mineral deposits in Ukraine can be implemented using the Micromine Beyond Pit Optimizer. The authors considered the parameters that affect the boundaries of the pit field and the optimization criteria.

## 1. Introduction

The technological solutions for the deposit development require an evaluation of the mining operations options. Pit design is a complex process accompanied by a multi-criteria evaluation of technological solutions. Relationships between the deposit structure, geological and hydrogeological conditions, economic indicators, and technological parameters of development are considered in the design.

During strategic planning, especially for deep pits, it is necessary to take into account changes in the economic component after a certain period, updating equipment taking into consideration new models. The planning also accommodates the reconstruction of the pits, which is associated with changes in cargo traffic, current development plans, changes in the angles of the sides of the pit, etc. Also, strategic planning is directly related to the quality of minerals and the volumes of their extraction for a certain period.

Most of Ukraine's iron ore pits are part of integrated mining and processing plants with mining and metallurgical complexes. Their work also affects the strategic planning of mining operations.

The complexity of pit optimisation is explained by the dynamics of economic parameters, geometric and quality features of mineralisation, especially with the complex distribution of different ore types, adjustment of deposit parameters during operational exploration. The construction of graphs and multivariate intermediate pit shells allows the Micromine software to greatly improve the decision-making regarding the final (optimal) shell of the pit field.

Mathematical models and methods, in contrast to traditional ones, allow to determine the optimal, in the sense of the given criterion of optimality, plan of mining operations in tabular form. However, they are used only in planning tasks, which can be formalized through simplifications and assumptions. Therefore, the original problem is reduced to a model of a mathematical type for which optimization methods have been developed and implemented by software, i.e., methods of solving problems of this type [1].

In scientific publications, models of mathematical programming (linear and nonlinear, continuous and discrete, deterministic and stochastic, single- and multi-criteria) are proposed as mathematical models. But in practice, the simplest of them are still used - linear one-criterion and, much less often - nonlinear one-criterion with simple nonlinearities in the constraints or the optimality criterion. The reason is the complication of substantiation (choice, creation) of a mathematical model; complication of the solution method, and, as a result, the lack of the software implementation of the problem or the complication of its modification and support.

Article [2] discusses mining technology for steep mineral deposits by steeply inclined sub-layers, considering the sub-layers location relative to ore body. The study grounds the phase and steeply inclined sub-layers parameters up to final pit depth. The sequence of mining steeply dipping seams at the open pit fronts depends on the mineralisation location at the footwall and hanging wall. The new proposed method of reactivation of non-operating edge of a deep iron ore pit will allow to increase the annual mining rate by 3-5 million tonnes and save a considerable financial and material resources.

Effective mining scheduling of steeply dipping iron deposits using sub-vertical layers based on mining experience of the Mining-and-Processing Integrated Works (MPIW), is considered in paper [3]. The scheduling workflow was organised from the standpoint of decision making under uncertainty. New mining scheduling methods of steep iron deposits by sub-vertical layers are proposed. To increase scheduling efficiency, initial technological data preparation is recommended using K-MINE software, and economic indicators and open pit contours determination is suggested using Deswik software. For the first time, a new mechanism of expedient spatial and temporal control of specific mining volumes by varying both the “time of start” and the power of layer mining is proposed for traditional open mining. This mechanism realises the piecewise stable dynamics of annual production and allows to solve the inverse problem – to determine the target values of spatial and temporal controlled parameters (“time of start” and power of layer mining) for the required ore and overburden mining rate. The proposed method of mining scheduling of steep iron ore deposits using sub-vertical layers has been successfully tested at the Poltava MPIW.

Micromine has a wide range of functionality for resource modelling and block model validation. Verification of input data and intermediate outputs at each stage of modelling ensures a correct resource model [4]. This is extremely important for further open pit design and mining operational scheduling.

The methodology of the medium-term mine planning procedure in the geological and mining information system Micromine in terms of a copper deposit of development using the room-and-pillar method is described in the work [5]. An emphasis is laid on accounting for various economic indicators when determining mining sequence and technology. The list of required data for implementing the procedure in mine planning in Micromine is presented.

Advanced computer aided methods such as the Micromine software are an important part of a complex research of various mineral deposit prospects. Article [6] analyses the prospects and resource (reserve) estimation for open pit and underground mining at the Berezkinskoye deposit. The deposit reserves were estimated for each ore type within the optimum pit shell accepted in the Final Feasibility Study. Section and plan georeferencing, vectorisation and geological database verification were performed using Micromine software.

Paper [7] systematises commonly used methods for mineral deposit modelling in the way of a step-by-step methodology. The modelling process of deposit geology on the basis of geological exploration data is considered in the geological and mining software Micromine. A block model of mineralisation is the result of this modelling. The most common sequence of mineralisation interpretation based on geological profiles is reviewed. The article describes the geological modelling algorithm, which includes data import and visualization in the Micromine software.

The ore quality requirements including cutoff grade, a minimum composite length, the maximum length of waste or sub-standard ore within the ore body, minimum grade×length [8]. Recently, mineral resource estimation has practice automation within specialized geological–surveying data processing software. The main subject in automation of the interpretation in the Micromine and the topic of this article is a delineation of mineralisation using the relevant quality constraints. The programmers implemented, since version 16, the ore occurrence algorithm based on the ore quality requirements using a method in a separate menu tab: Drillhole/ Compositing/ Grade.

Modern trends in the development of information support for mining technology dictate the need for a comprehensive solution of technological problems based on a single software platform, which provides the ability to quickly adapt the basic functionality and develop a new one to the conditions of a mining enterprise [9]. In this case, the ideology of building and developing information systems is of key importance. The modeling technique proposed by the authors is suitable for solving the current problems of the geological service of mining enterprises. The developed software in Micromine software is being tested at mining enterprises and is being improved to better meet the needs of geological services.

The resource estimation of the Borov Dol deposit was carried out mainly using AutoCAD software, and these results were officially confirmed in the Republic of North Macedonia [10]. The latest estimation using Micromine provides wider use of source data of detailed geological surveys and fast correlation between metals and associated elements. Micromine results have good correlation and compatibility with similar results obtained by the method of geological sections using the AutoCAD software package (difference 1.21%).

Micromine is one of the world’s leading producers of software for the Geological and Mining Sector and has comprehensive solutions for exploration, modeling, resource estimation, mine design, and strategic scheduling management. The considered functionalities in this article [11] are the geological and economic assessment of mineral deposits. This advanced software allows to optimize expenses for geological and economic evaluation of mineral projects and allows to obtain results by the generally accepted international standards of geological reporting (JORC Code, NI 43-101 etc.) and modern best practices in geology.

The purpose of the article [12] is to identify prospective sites within the Syrymbet deposit on the basis of systematisation and complementation of mineralisation localisation factors and criteria. To modelling mineralisation and three-dimensional distribution of grades, Micromine modelling methods were used.

Geographic Information Systems (GIS) software nowadays are used in almost every area of industry and economy, central and local government, and public and private services. Having as the main purpose good management and decision-making in the field where applicable, these systems and their application generate the integration of the tabular data with their geospatial position. The application of GIS software in 3D Modeling and interpretation of iron-nickel deposit in Skroska is part of a study aimed at creating an innovative method by using Micromine software [13].

In this paper [14], the method for determining the parameters of the working area needed for forming an internal dump after working off the open pit of the first turn is improved. The results of the research and the obtained dependencies allow us to improve the methodology for calculating the parameters of the working areas of deep open pits taking into account the future formation of internal dumps on them.

Determining the slope angle of the pit is one of the factors affecting its dimensions during planning. The slope angle depends on the physical and mechanical properties. The slope angle affects the volume of overburden rock removal. The development of mining operations inclined layers with a significant angle to the horizon is essential task of mining operations [15]. Open pit slope formation with high slope angles allows to postpone most of the overburden stripping mining to a later stage of deposit development. The technology and dependencies are defined by layer height during open pit formation by steep layer slopes.

The slope angles of especially deep iron ore pits are limited by the rules [16]. During the design, it is necessary to take into account the possibility of further expansion of the final boundaries of the pit as the field is explored, for which it is recommended to rebuild the prospective contour of the pit along the surface, taking into account the industrial use of off-balance sheet mineral reserves. Provided ensuring the pit with mineral reserves for a long period of operation, the rationality of selecting intermediate

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contours of the pit with reserves that ensure operation during the first 15-20 years under more favorable development conditions should be determined.

Digitalization is utilized widely in the modern ore pits of Ukraine. Strategic planning departments use modern domestic and foreign software complexes. First of all, this is since the qualitative composition of the deposit is very different in the layers. For example, the iron ore content of deposits in Ukraine can vary from 15 to 37% in different horizons. The purpose of the work is to determine the effective strategic planning of open-pit mining operations using the optimizer on the example of the Micromine software complex.

## 2. Methods

Open pit shell optimisation is considered to be one of the major challenges in mining industry. Lerch and Grossman in 1965 created the first optimisation method that could be applied to large open pits in a reasonable time [17]. Despite the availability and development of a set of other pit optimisation algorithms [18, 19], the Lerch-Grossman method is still considered to be the most optimal and is widely used in open pit design software, including Micromine [20], as an industry standard.

The Lerch-Grossman algorithm allows to determine first the ultimate and then the optimal pit shell. The ultimate pit shell is a pit which gives the highest possible undiscounted surplus between net revenue and total operating costs but does not consider scheduling constraints and discounting. The ultimate pit provides data for economically recoverable reserves and for strategic, intermediate and operational mining planning. A subsequent analysis of nested pit shells provides an indication of the future discounted financial cash-flows of each nested pit and allows the optimal pit shell to be selected. The aim of the algorithm is to develop a pit shell which maximises the difference between the total cost of commercial components of the deposit, and the cost of mining and extracting the commercial and non-commercial components.

The Lehrch-Grossman methodology is based on the value of each block planned for mining. Ore block values will be positive and based on the value of the recovered or minus any expenses associated with processing, sales, and other costs. Waste blocks will have a negative value which is based on the costs associated with excavation and haulage (figure 1). In addition, the Lerch-Grossman method requires, for each block in the model, details of the other blocks that need to be removed to uncover it. The optimization process can be iterative. After results analysis, the input parameters can be revised and refined, and the optimization can be repeated [21].

The main optimization results are:

- Reports including details of data pre-processing,
- Staging Points – File of centres blocks coordinates for each mining stage,
- Staging Wireframes – Wireframes for generated pits (figure 2),
- Block Model Attributes – Fields in the block model updated with results from optimisation.

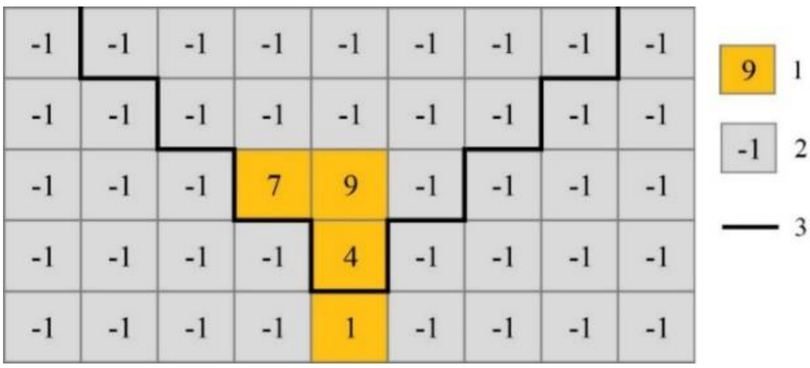


**Figure 1**. Simplified Visualization of the Lerchs-Grossmann algorithm. Legend: 1 – mineralized blocks with estimated value, 2 – waste blocks with estimated value, 3 – open pit boundary.

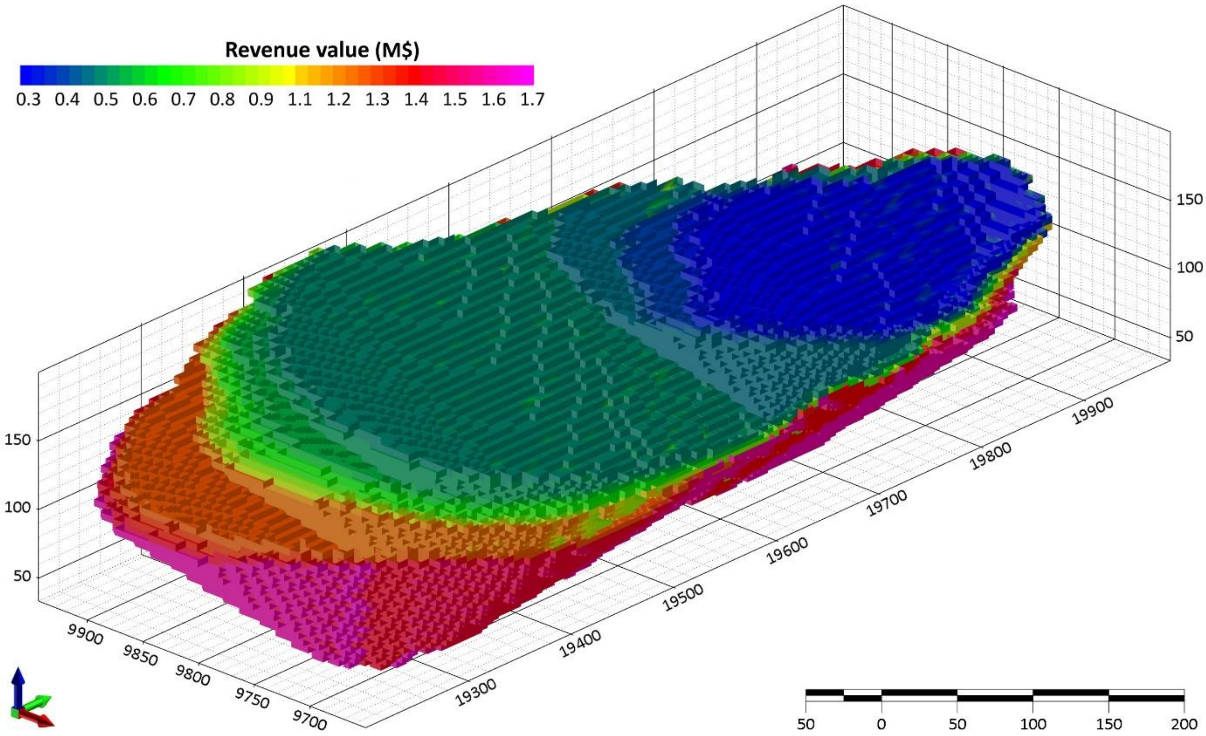


**Figure 2**. Nested pit shells example.

In general, the input parameters are divided into optimization parameters and results analysis parameters. Optimization input parameters include mining and geological, design, processing, and economic parameters (table 1).

As a result of the optimization, ultimate pit is created, and nested pit shells for different profit levels are created. In order to select the optimal pit shell, all the shells are analyzed by the relevant parameter set (analysis parameters or parameters of optimality):

- Finances – capital costs, expenses and discount rate,
- Rates – mining, processing and selling rates,
- Stockpiles – maximum size of stockpile for each commercial component and rehandling cost.

In addition, the mining sequence should be specified, namely Best Case, Worst Case or Constant Lag. If necessary, all three sequences can be analyzed for comparison purposes.

Best Case is a mining sequence where each shell is mined out completely before proceeding to the first bench of the subsequent pit shell (figure 3). Ore and waste from the pit shell is mined at the same time. In this way, the highest value ore is mined as early as possible maximising cashflow. Usually this sequence suited to large pits.

Worst Case is a sequence where each bench is mined completely before the next bench is started. Entire bench across all pushbacks is mined prior to proceeding to the next bench. This results in pre-stripping the entire deposit, defers ore production and minimizes the cashflow by placing stripping costs up front and delaying revenue. Typically suited for small pits (figure 4).

Constant Lag – A bench interval (vertical lag between benches) is defined between pushbacks such that once the fixed number of benches have been mined in an interior pushback then mining can commence on the subsequent pushback. Lag = 0 makes the scenario the same as worst case while increasing the lag brings it closer to the best case (figure 5).

Detailed reports of the optimisation results analysis provide information on pit shell mine life, waste and ore tonnage and grades, recovery, revenue, cost, profit value, and the NPV (Net Present Value) etc. These results can also be presented in the chart view (figure 6).

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**Table 1.** Input optimization parameters.

| Group | Parameter | Description |
|---|---|---|
| **Mining and geological** | | **Specifies how the open pit will be modelled** |
| | Block Model | Block model, source fields for key properties (e.g. volume, tonnage, grade), optimisation boundaries and parameters |
| | Ore types | Ore types of the deposit |
| | Valuable components | Elements produced from the deposit |
| | Rock Types | Types of rocks that have different mining cost adjustment factors or rehabilitation costs, etc. |
| | Dilution and Recovery/ Losses | The dilution factor specifies the amount of waste that is mined with ore, Mining Recovery is a percentage of ore recovered, Mining losses are ore lost during the mining activity |
| | Zone Defaults | Density, Mining and Processing Cost Adjustment Factor, cost of rehabilitation values that apply in absence of block-specific information for defined zones |
| **Design** | | **Requirements for the open pit design** |
| | Slope Restrictions | Slope angles specified for defined regions |
| | Mining costs | Costs for ore and waste mining |
| | Exclusion Zones | Zones to which generated stopes or pits should be confined or from which they should be excluded (such as buildings or protection zones) |
| | Staging | Revenue Adjustment factor Increment for generate nested pit shells |
| **Processing** | | **Parameters for each processing method** |
| | Processing Cost | The cost per unit mass or volume of processing material by the facility |
| | General and administration cost | The additional unit cost (per unit of contained element) of processing the element from the ore |
| | Processing Recovery | The fraction of the total amount of element that is extracted from ore |
| | Threshold | The grade below which an element cannot be recovered |
| | Additional processing cost | Additional specific costs (per unit of contained element) for recovering of the element by an additional processing stage |
| **Selling** | | **Specifies parameters for each customer and element** |
| | Element | The element purchased by the customer |
| | Price | The price per unit of element paid by the customer |
| | Selling cost | The cost per unit of element incurred when selling the element to the customer, including taxes |

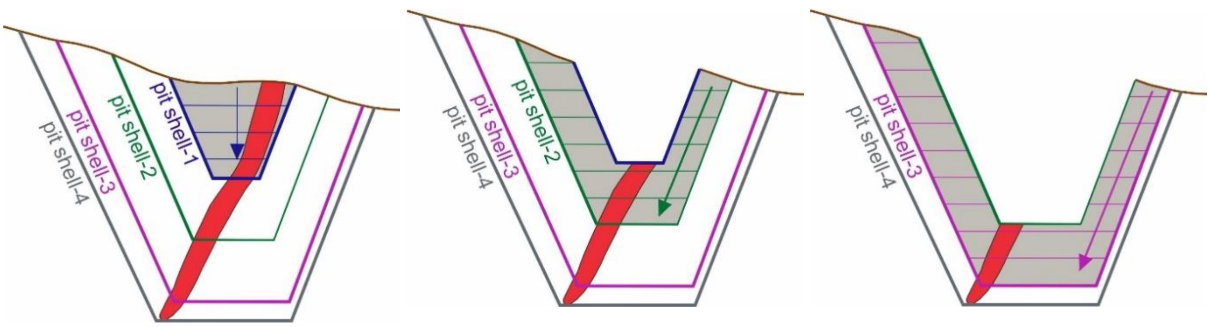


**Figure 3**. Best Case Mining Sequence.

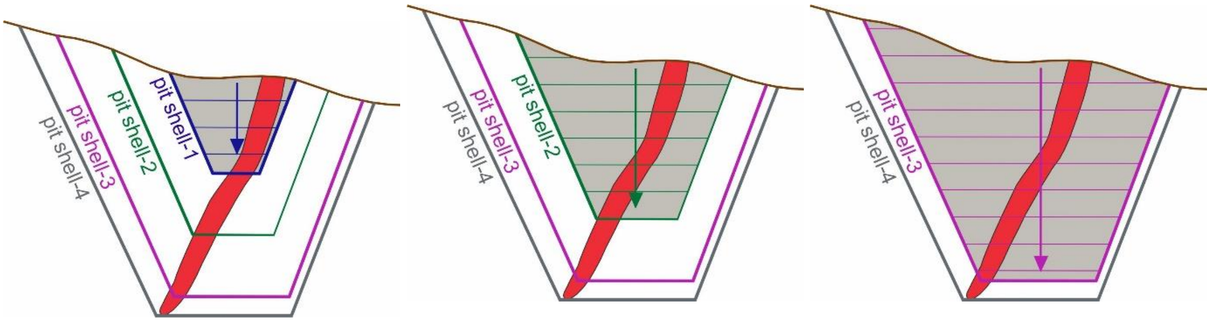


**Figure 4**. Worst Case Mining Sequence.

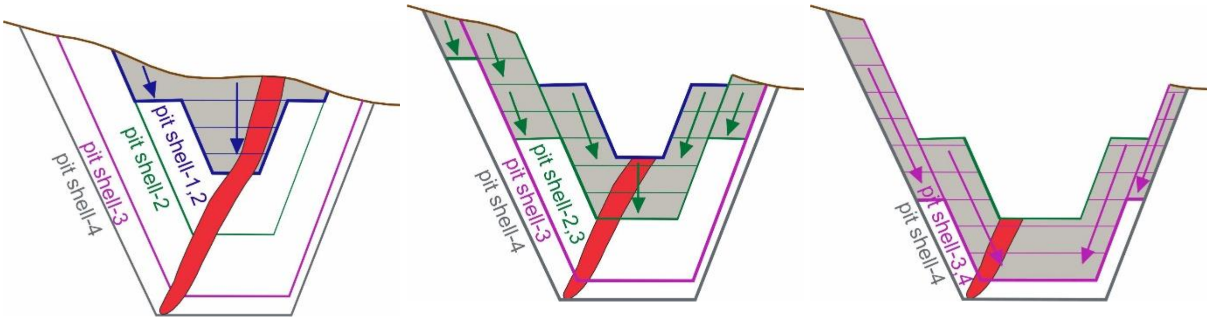


**Figure 5**. Mining Sequence with Constant Lag.

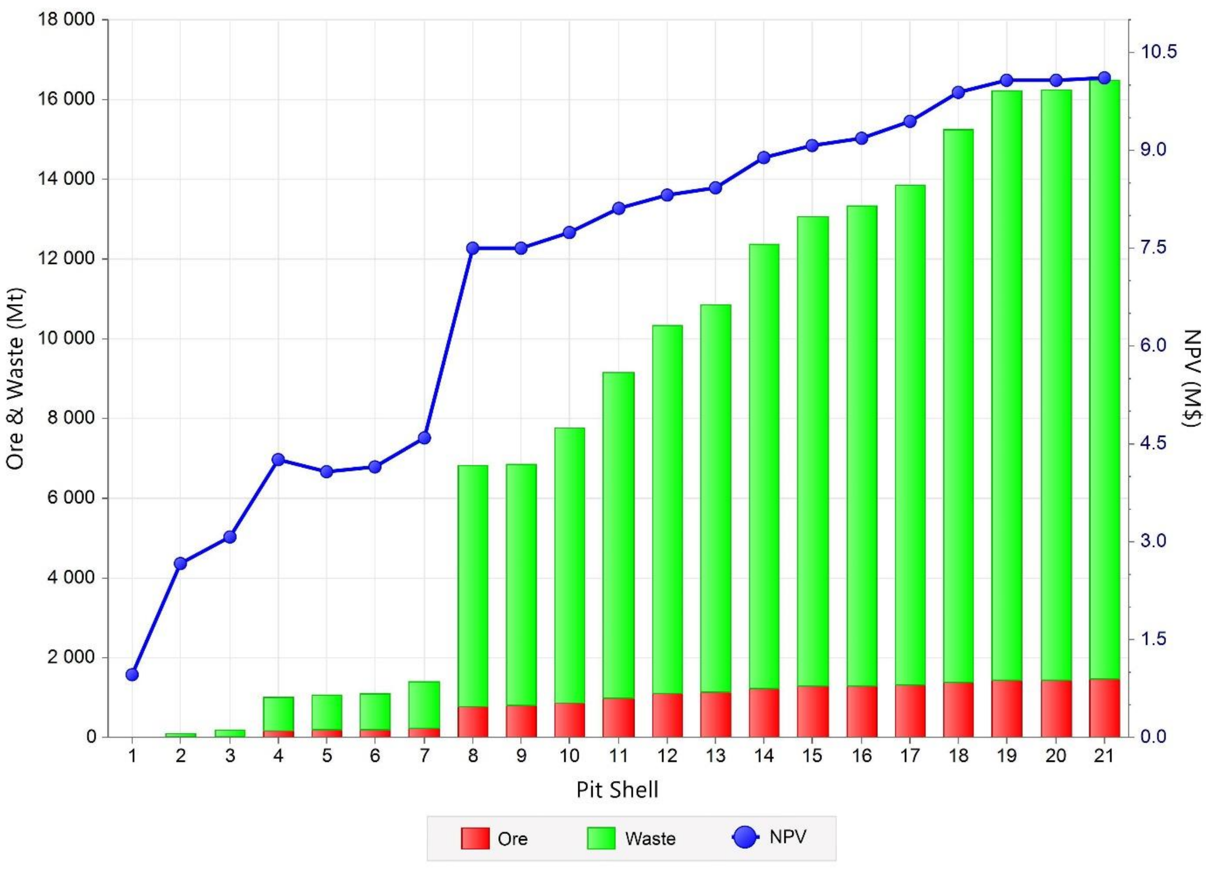


**Figure 6**. Optimization results chart (Ore & Waste vs NPV).

The following data series can be included and will be added to the chart in the order in which they are specified in the grid list:

- Cashflow – cumulative sum of undiscounted net revenues;
- Present Value – net revenue, converted to present value by applying discount rate(s);
- Waste / Ore / Total Volume and Tonnage;
- Strip Ratio – Ratio of ore to waste of mined material;
- Grade – Average grade of each element for period;
- Metal – Mass of valuable component;
- Revenue – Revenue from all valuable components;
- Mining cost.

The optimisation results allow us to select the optimal (most economically feasible) pit shell and create a preliminary strategic mining plan for the entire life of the pit. For each period, a set of parameters can be assessed, as described earlier. This is important for understanding the development trends of the enterprise.

## 3. Results and discussion

The Kryvyi Rih basin and Kremenchuk district form a single Kryvyi Rih-Kremenchuk zone, where the bulk of iron ore production in Ukraine is carried out. The main mining operations are provided at 7 mines and 13 open pits.

Northern MPIW's raw material base is the currently operating open pit № 1 (Pervomaiske deposit) and open pit № 2 (Hannivske deposit). The iron content of quartzite in the Pervomaiske open pit is 35.6%, and 31.6% in the Hannivske open pit. The depth of reserves at the Hannivske deposit is 500 meters from the surface in the southern part and 300 meters - in the northern part. At the Hannivske open pit, the iron content of the extracted ore is 35.75 ± 0.25% total iron and 25.90 ± 0.2% magnetite-bound iron. The content is unevenly distributed across the horizons and layers of extraction. Such a deposit should be subject to a reassessment of the balance sheet ownership of reserves in a market economy.

Poltava MPIW is developing the Horishni Plavni and Lavrykovskyi deposits. The design depth of the open pit is 240 to 700 meters. The magnetite quartzite mined at the deposits is divided into two types: red-banded and grey-banded. Red-banded magnetite quartzites are confined to the lower and upper K22 units in maximum quantities. They are the richest in iron, with a total iron content of 35.9% to 37.3%. They are easily enriched. Grey-banded magnetite quartzites make up the middle K222 package. Compared to red-banded quartzites, grey-banded quartzites are somewhat lower in iron, with a higher content of silicon and carbonates. The average content of total iron is 34.4% to 35.7%, and magnetite is 26.6% to 28%. In addition to ore with high iron content, the deposit structure includes layers with low iron content, and the ore is blended for further beneficiation. The depth of development at the deposit has already been revised to 650 meters. Whether such a depth is optimal in terms of extraction is a question that can be resolved by using the optimization of the open pit space for strategic planning.

Central MPIW's raw material base includes open pits № 1 (Hleiuvatskyi deposit), № 3 (Petrovskyi deposit), which are currently in operation, and open pit № 4 (Artemovskyi deposit) (figure 7).

The Petrovskyi deposit of Central MPIW is a steeply dipping deposit producing ore with a total iron content of 32.1%. The depth of estimated reserves is 300-500 meters.

Typically, the depth for such an open pit is determined by the horizontal thickness of the deposit, the slope angles of the pit sides, and the cost of excavation, stripping, and dumping. It would also be necessary to consider the value of each layer of minerals, the cost of processing, and the method of processing. A multi-criteria approach may yield a different result in terms of the design depth of the pit.

Open pits № 2 and № 3 at ArcelorMittal Kryvyi Rih are used to mine the Novokryvyi Rih iron ore deposit. Open pit № 2 has a design depth of 415 m, and № 3 has a design depth of 500 m. The average grade of iron bound to magnetite is 28.9%, and the total iron is 37.4%. The open pits border on other open pits located very close by, for instance, the boundaries of Pivdennyi MPIW's open pit are 50 meters from open pit № 3, and ArcelorMittal Kryvyi Rih's open pit № 1 borders open pit № 2 to the west, with the Inhulets River flowing nearby. The optimization program for such deposits should also take into consideration the limitations of the sides. It is due to the proximity of institutions, canals, rivers, buildings, and other security facilities.

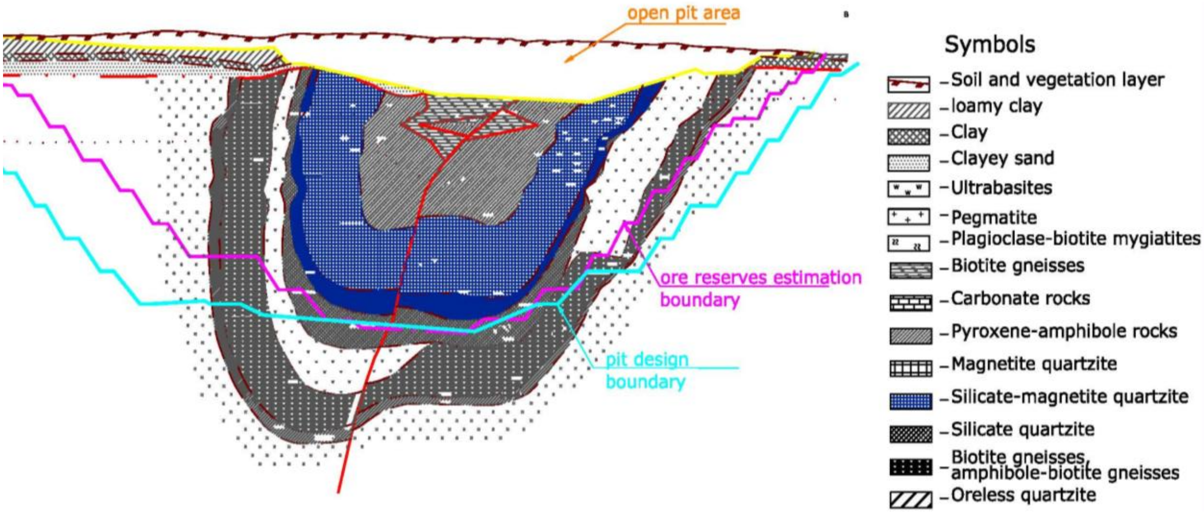


**Figure 7**. Geological section of the Central MPIW open pit.

According to these parameters, most iron ore pits in Ukraine have a significant design depth, with deposits represented by steeply dipping deposits with different iron contents. When considering the further development of such pits, and their reconstruction, it is necessary to determine their optimal design parameters on time.

Deep open-pit mines can be developed for decades. Mining conditions, the cost of ore extraction and overburden removal, pit side angles, the cost of mineral processing, and prices for finished products change, and therefore it is necessary to review and determine promptly the optimal values for ore deposit development. The Micromine software provides such capabilities, where optimization options and analysis of optimized pit shells allow to choose a deposit development option (figure 8).

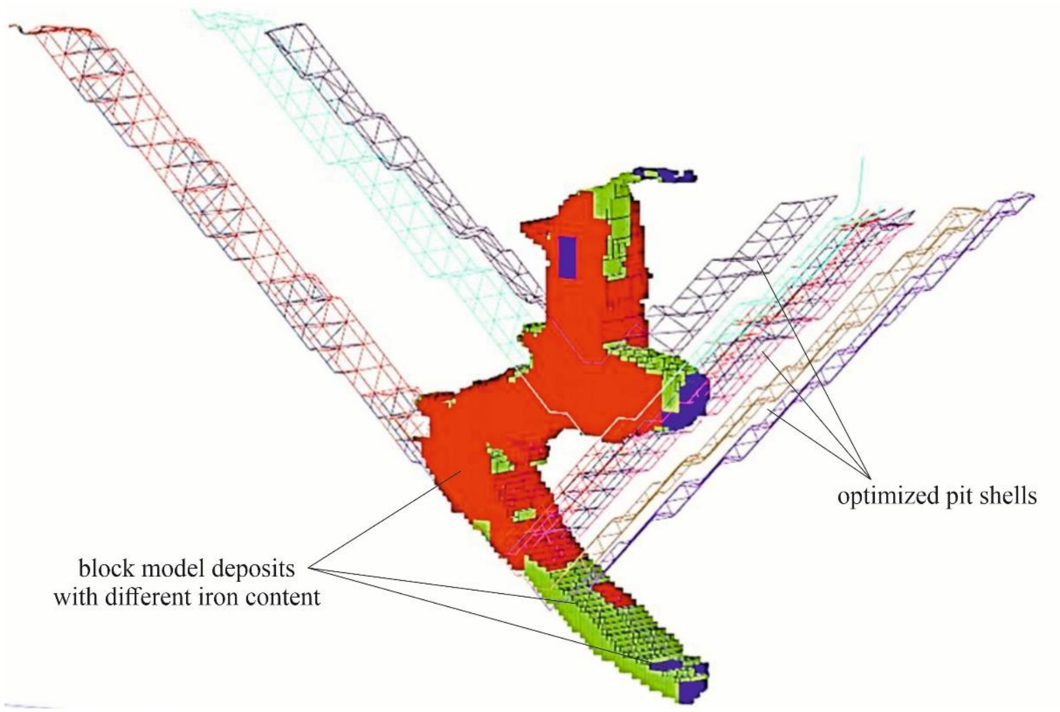


**Figure 8**. Optimised pit shells 3D section.

## 4. Conclusions

Strategic planning of open pit mining operations using the Micromine Beyond optimizer begins with the creation of a boundary shell of the pit, as well as nested shells with different levels of profit. The Optimizer's Analysis mode allows to set planning constraints, time limits, and discount rates. Determination of the future discounted financial cash flows of each nested pit helps identify the optimal pit shell. The pit shell is only a conventional boundary that will allow a mining company to make a profit when extracting ore. The analysis is based on a scenario with three different mining sequences: the best case, the worst case, and the case with a constant step. Net Present value (NPV) is a key component of optimization and can be used to calculate the long-term profitability of a mining project. The optimization process can be iterative, when the outcome analysis allows to revise and refine the input parameters and repeat the optimization again.

The development strategy of Ukrainian mining enterprises requires adjustments, especially for large open pits. An open pit optimizer at iron ore deposits can be an effective tool to correctly determine technical boundaries of the open pit, allocate finances, and possible directions for the development of mining operations (strategic planning).

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