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## Opportunities and advantages of GIS for building three-dimensional models in mining

**Abstract.** The relevance of the study is driven by the need to optimise mining, monitoring and risk management, which requires the rapid introduction of advanced technologies to ensure the sustainable development of the mining industry. The purpose of this study was to analyse a new approach to the use of geographic information systems. The methods used include observation, description, comparison, modelling and other methods. The study analysed a new approach to the use of geographic information systems in mining to build three-dimensional models. By implementing this methodology in mining practice in Ukraine, significant positive changes have been achieved: the risks of emergencies have been reduced, mining processes have been optimised, and overall productivity has increased. It has also been shown that the use of geographic information systems can increase the accuracy of mining planning and reduce the cost of mining operations. Compared to traditional modelling methods, the new GIS-based approach provides more accurate and reliable data on geological structures and mineral distribution. The study has confirmed that the introduction of such technologies can significantly increase the competitiveness of mining companies by providing them with tools for more accurate forecasting and management of mining processes. The practical significance of this study is to establish an effective method of using geographic information systems to build three-dimensional models in mining, which opens new opportunities to improve the efficiency and safety of mining operations, in particular in Ukraine, contributing to the sustainable development of the industry and the country's economy

**Keywords:** exploration network; technology; mining; minerals; computer modelling; maps

### Introduction

The study of the use of geographic information systems (GIS) in mining is extremely important in terms of improving the efficiency and safety of mining operations, which are key aspects for the sustainable development of the industry. GIS enables the analysis, modelling and forecasting of various geological and mining processes, which allows for optimising mine locations, planning to mine operations, monitoring the environment and

managing risks. Given the strategic importance of mining for the country's economy, the development, and improvement of GIS applications in this area is essential for the competitiveness and sustainable development of the mining industry. The research was aimed at identifying the optimal methods of using GIS to build three-dimensional models in mining to improve the efficiency and safety of mining operations. This involves

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developing and implementing new technologies for accurate geological structure modelling, mineral resource identification, and mining process optimisation. It also includes establishing methods for monitoring and risk management. It should be borne in mind that the methods of using geographic information systems in mining need to be adapted to the conditions of specific regions, including Ukraine, due to its unique geological and geographical features. For example, when implementing such methods in mining projects in the Carpathians, it is necessary to consider the peculiarities of the mountainous terrain and the location of water sources, which may affect the risks of environmental disruption and employee safety. In addition, in areas with high seismic activity, such as the western regions of Ukraine, it is important to develop methods that consider the possible effects of earthquakes on mining facilities and infrastructure.

According to the study by N. Zuievskaya & T. Hrebeniuk (2024), the integration of geographic information systems in mining helps to reduce risks and improve the accuracy of mineral location. This integration allows miners to plan their work more efficiently, avoid unforeseen situations and optimise mining processes. The study highlighted the importance of using modern technologies to increase productivity and safety in mining. In their work, S. Andrieiev *et al.* (2021) investigated the need to develop new methods for analysing geographic data to build three-dimensional models in mining. Existing data analysis methods may not be effective enough to fully utilise geographic information in mining. The study highlighted the importance of finding new approaches to processing and analysing geographic data to build more accurate and reliable three-dimensional models in mining.

The study by E. Ivanov *et al.* (2023) examines the importance of using geographic information systems to optimise the location of mining facilities and planning of mining operations. The use of GIS allows for more efficient placement of mining infrastructure, reducing costs and risks. The study emphasised the importance of GIS as a tool for improving the efficiency of mining operations and reducing the negative impact on the environment. Yu. Velikodsky *et al.* (2023) point out the possibilities of using GIS to monitor and reduce the environmental impact of mining. GIS can be a powerful tool for systematically tracking changes in the natural environment and effectively managing the impact of mining activities. The study emphasised the importance of introducing GIS into mining to ensure sustainable development and conservation of natural resources.

A study conducted by M. Lubishtani & F.B. Lubishtani (2024) highlights the use of GIS in optimising the selection of locations for solar and wind power plants. By analysing geodetic parameters, such as elevation, land cover, and geographic coordinates, GIS aids in identifying the most suitable areas for energy

installations. The integration of GIS in decision-making processes enhances the efficiency of site selection, leading to more effective management of renewable energy projects. The study underscores the importance of modern technologies, such as GIS, for improving the accuracy of planning and maximising the potential of renewable energy resources. In the work of B. Sobko *et al.* (2021), the authors explored the possibilities of using geographic information systems to reduce mining costs and optimise resource use. GIS can be effectively used to plan mining routes, locate infrastructure, and optimise workflows in mining. The study highlighted the importance of using modern technologies, such as GIS, to ensure effective management of mining projects and reduce their costs.

The purpose of this study was to evaluate a new approach to using geographic information systems to create three-dimensional models in mining to improve the productivity and safety of mining operations in Ukraine.

## Materials and Methods

The Surpac integrated system enabled the creation of a digital deposit model, taking into account the latest advancements in geotechnology, and streamlined the process of identifying an efficient method for volumetric modelling of mining objects in open-pit operations. Geostatistical 3D modelling comprised various essential steps: establishment of a database, creation of a geometric orebody model, composition and delineation, statistical analysis, block modelling, and resource estimation. Additionally, by integrating with other software tools, Surpac became part of an advanced mining automation system, enhancing the efficiency and accuracy of the production process. Block modelling generated a three-dimensional representation of the sites by filling in a three-dimensional wireframe and dividing the terrain into elementary blocks. The block model was then imported into GEOVIA MineSched for analysis, where mining zones were defined, and mining equipment was allocated. The structure of the block model is similar to a table, with each column representing an object's attributes and each row representing a record.

The method of observation used in the study was to track mining processes and their impact on the environment. This method allowed for the collection of thorough data on various aspects of mining activities, such as the size and nature of explosions, changes in geological structures, and the quality of materials produced. This information has been used to develop strategies to reduce the negative environmental impact of mining operations and improve the overall efficiency of natural resource use.

The description method was used to describe in detail each stage of the mining process, from prospecting for deposits to production and processing of minerals. This made it possible to understand the geological structure of the region, identify potential risks and

determine the best strategies for their management. A detailed description of mining operations provided the basis for further analysis of the efficiency and safety of mining sites and helped to develop recommendations for their optimisation and improvement.

The benchmarking method helped to identify the advantages and disadvantages of different approaches to mining, including the use of geographic information systems. This allowed identifying the best methods and strategies that can be applied to improve the efficiency and safety of mining operations. In addition, the benchmarking method allowed defining potential opportunities for further development and improvement of mining technologies.

The modelling method was a useful tool for forecasting various scenarios for the development of mining operations and their environmental impact. The modelling method gave the possibility to develop virtual models of mining sites and operations, which allowed effectively determining optimal resource management strategies and minimising negative environmental impacts. Furthermore, the modelling method has become the basis for exploring the possibilities of introducing new technologies and approaches in mining.

The measurement method provided precise data on the geometry of deposits, their dimensions, and the location of various mining facilities. Laser scanning made it possible to create detailed three-dimensional models of mines, walls, ceilings and other elements of mining structures with high accuracy. Photogrammetry was used to examine photographs from different angles to measure the dimensions and distances between objects, while geodetic measurements helped to obtain data on heights, angles, and distances across the mine site. This precise data helped to build more detailed engineering solutions, improve planning of mining operations and reduce risks during operations. The use of measurement in mining has enabled a more complete understanding of the geometry of deposits and the efficient management of mining resources to achieve better results.

## Results and Discussion

Geographic information systems are computer systems created to gather, store, analyse, and visualise geospatial data. Geospatial data includes information that has a spatial location on the earth's surface, such as geographical coordinates, heights, location of objects. GIS allows using this data for a variety of analytical operations, visualising geographical patterns and solving geospatial problems in various fields, including geology, geodesy, ecology, architecture, transport, and many others. GIS consists of three main components: hardware, software and data. Hardware includes the computers and other devices used to run GIS, such as personal computers, servers, and GPS. Software is used to collect, store, analyse and visualise geospatial data, including applications for creating and editing maps,

analysing spatial relationships and modelling. The data used in GIS includes geographic coordinates, attribute data about objects, elevation data and satellite imagery, which are the main inputs for mapping and analysis. GIS works by integrating data from a variety of sources, such as maps, satellite imagery, GPS data and census data. This data is used to create maps, layers, and models that allow users to understand and analyse spatial relationships. GIS allows visualising data in the form of maps, edit and analyse geographic information to make management decisions, plan routes, determine optimal locations for facilities, and much more.

The principles of GIS can be summarised in three key aspects. GIS operates with spatial data, which means using information that is geographically located, such as map coordinates, geographical objects and their properties. Furthermore, GIS can analyse this data, revealing various patterns, relationships, and trends occurring in space. Finally, GIS allows for the visualisation of geospatial data in maps, models, or other visual representations, which helps users to better understand spatial relationships and make informed decisions. GIS diagrams represent different types of visual representation of geospatial data. There are several various types of GIS diagrams that are used to represent different aspects of geospatial information. Common types of GIS diagrams include point diagrams, which are used to display point data such as the location of trees or buildings; line diagrams, which are designed to represent linear features such as roads or rivers; and polygonal diagrams, which are used to display areas or zones such as countries or parcels of land. Each type of GIS schema has its own unique properties and applications in the analysis and visualisation of geodata. GIS offers several benefits that make them indispensable for a variety of activities. They increase efficiency by simplifying and automating tasks, which saves time and money and improves decision-making. GIS provides increased accuracy of analysis by giving users access to up-to-date and accurate data, which helps in making informed decisions. In addition, they facilitate communication by visualising geographic information on maps, which promotes better communication between project participants and facilitates easy collaboration.

Geographic information systems are used in many areas of activity, including mining, urban planning, forestry and agriculture (Shvorov *et al.*, 2018). GIS provides convenient and efficient tools for analysing and managing geographic information, helping to improve processes in these industries. In forestry, they are used to managing forest resources and monitoring forest fires. In agriculture, GIS helps with soil mapping, crop rotation planning and yield monitoring. In urban planning, they are used for city planning, infrastructure development and environmental monitoring. Geographical information systems offer great opportunities for miners to obtain detailed information about the location of various

elements of mining infrastructure and mining deposits. Thanks to GIS, miners can analyse the location of various components of mining facilities in virtual space, which contributes to a better understanding of the geological features and structures of the territory (Krawczyk, 2023). This is important for effective planning and development of mining strategies, as it allows for a variety of geological and geomorphological conditions to be considered. In addition, GIS provides miners with an opportunity of considering various risk and safety factors in mining operations. Analysis of spatial data helps to identify potential hazards and determine the best ways to avoid or minimise them. This helps to improve the safety of working conditions and reduce the likelihood of accidents. Thanks to spatial analysis using GIS, miners can efficiently plan and execute various mining operations, optimising resource use and increasing mining productivity. In general, the use of GIS in mining allows for a deeper understanding of natural processes and maximising the potential of mining resources, contributing to the sustainable development of the industry.

One of the key benefits of visualisation is the ability to display complex geological structures in three dimensions. This gives miners the ability to virtually delve into the depths of the earth and explore the location of mineral deposits, which contributes to a better understanding of geological conditions and the formation of mining strategies. In addition, GIS visualisation allows miners to plan and manage mining operations more efficiently. By displaying various elements of mining infrastructure and production facilities on three-dimensional models, miners can carry out more accurate production planning, develop optimal mine layout strategies and development routes. By visualising data using GIS, miners can implement more transparent and predictable management of mining processes. Visualisation graphically displays complex geological and mining data, making it more understandable and accessible for analysis and decision-making (Yousefi *et al.*, 2021). Thus, visualisation of geological structures and mineral deposits using GIS is an integral part of efficient mining production, which contributes to increased productivity and reduced risks in the mining industry.

One of the main advantages of using GIS in modelling is the ability to display the location and structure of mineral deposits in three dimensions. This gives miners the ability to virtually explore the depth and size of rock deposits, which is key to developing mining strategies and determining the best mining methods. In addition, GIS provides miners with an opportunity of optimising mine locations and developing optimal mining strategies. The analysis of spatial data allows for a variety of factors, such as sediment depth, geometry, and geological properties, to be considered to determine the optimal location of infrastructure and equipment (Smith *et al.*, 2023). Finally, GIS can be used

by miners to plan long-term investments in mining projects, considering the geological and geomorphological features of the area. Modelling the operation of deposits helps to make informed decisions on the development and operation of mining facilities, ensuring optimal use of resources and maximising product yields. Thus, GIS plays an important role in modelling the operation of mineral deposits, providing miners with the means to effectively plan and manage mining processes, which contributes to the increase in productivity and efficiency of mining production.

GIS allows for real-time tracking of various geological and hydrogeological processes that can be a source of risk to mining operations. For example, they can monitor ground movements, changes in topography and hydrogeological conditions, which can prevent the possibility of landslides, flooding or other negative events. GIS can analyse and predict risks associated with the location of mining infrastructure (Ruhela *et al.*, 2022). They help to determine the optimal locations for mines, equipment and other mining facilities, considering potential hazards. GIS can be used to predict and model different risk scenarios and develop risk management strategies. They can consider various factors, such as geological conditions, climatic factors and other variables that affect risk, which helps to develop effective measures to minimise risks and ensure safe working conditions in mining. Therefore, the use of GIS for monitoring and managing risks in mining is critical, as it helps to ensure safe working conditions, reduce the likelihood of hazardous situations and increase the efficiency of mining operations.

GIS allows miners to analyse the geographical and geological features of the region where mining infrastructure is planned to be located. This includes studying the terrain, geological structure, climatic conditions, as well as accessibility to transport networks and other infrastructure facilities. Analysing these factors helps miners determine the best locations for mining facilities. GIS allows modelling different scenarios of infrastructure placement and assessing their impact on various aspects of mining operations, such as productivity, safety, and cost-effectiveness (Hosseinpour *et al.*, 2022). This allows miners to make informed decisions about the best infrastructure location. Finally, the use of GIS in the process of optimising the location of mining infrastructure contributes to improved planning and management of mining operations. This makes possible the efficient use of resources, reduction of costs, and increased overall productivity of mining enterprises. Hence, GIS holds significance in optimising the positioning of mining infrastructure, assisting miners in making well-informed decisions regarding optimal locations. This ensures enhanced efficiency and competitiveness for mining companies.

GIS can automate certain operations that used to require considerable effort and time. For example, GIS

can be used to automatically analyse geological data and determine the best locations for mining facilities. GIS can improve the planning and coordination of mining operations. This is achieved through the ability to create detailed three-dimensional models of mining facilities and their environment (Choi *et al.*, 2020). Such models allow miners to better understand the topography of the area, the location of minerals and other factors affecting mining processes, which in turn contributes to more accurate and efficient planning of operations. Finally, the use of GIS helps to reduce losses and optimise the use of resources in mining. GIS allows miners to track and control the movement of minerals, determine optimal transportation routes, and plan the use of equipment and labour. This helps to reduce costs and increase productivity of mining companies, which has a direct positive impact on their competitiveness and profitability. Therefore, the use of GIS in mining is a key factor in improving the efficiency of mining processes, which contributes to better management and workflows, reducing losses and optimising resource use.

Surface mining is a form of mining activity that takes place on the earth's surface and involves the operation of open pit mines. This type of mining activity is characterised by the fact that it takes place directly on or slightly below the surface of the earth, i.e. without the need for adits or shafts. Surface mining is a specific form of mining activity that takes place on or slightly below the surface of the earth. It encompasses a variety of mining activities conducted in the open, without the need for adits or shafts to access the minerals. Among the most common methods of open pit mining are quarries, open pits and surface mining. Quarries are large open pit mines where minerals are extracted directly from the surface of the earth. Open pits, in turn, are mining operations that also take place on the surface. Surface mining usually involves the extraction of metals such as gold, silver, copper, nickel and other minerals. These forms of open pit mining have their own specific features and requirements, but they are all characterised by openness and the absence of the need to construct mines or adits for mining. This method of exploitation has its advantages and limitations and is used in various mining industries for the extraction of various minerals. In open pit mining, there is no need to construct or operate adits or shafts, as mining operations take place directly on or slightly below the ground surface. This feature is a key difference from other mining methods, which often require the construction and operation of deep adits or shafts to access mineral resources. The absence of the need for adits or shafts in open pit mining simplifies the operation process and reduces the cost of building and maintaining mining infrastructure. Instead, minerals are extracted directly from open pits, quarries, or other open workings located on the surface of the earth. This feature makes open pit mining attractive to businesses, as it is often more

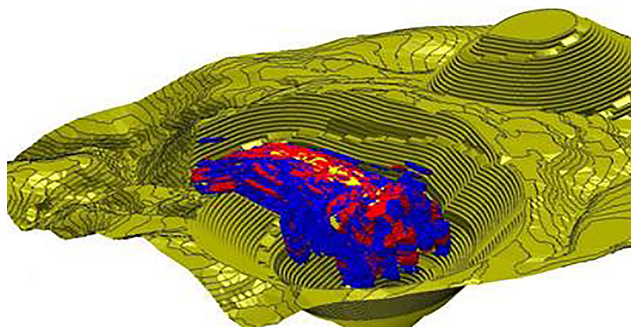
efficient and cost-effective, especially when extracting large volumes of minerals. In addition, the absence of mines helps to reduce the environmental impact and risks associated with the construction and operation of mining infrastructure.

Large-scale operations are one of the key features of open-pit mining. This means that this method of mining allows large areas to be covered for the extraction of minerals such as coal, metals, or construction materials. One of the advantages of large-scale operations is their ability to provide large volumes of production, which makes them particularly attractive to the mining industry. This is particularly important when a large demand for minerals needs to be met or when there is a need to develop infrastructure for construction or other needs. Large-scale operations also allow for efficient use of resources, ensuring that the areas for mining are optimally utilised. This may include spreading a variety of mining operations over large areas to maximise productivity and efficiency. In addition, large-scale operations can contribute to economic benefits by ensuring that economies of scale arising from large volumes of production can be taken advantage of. This can help reduce mining costs and increase the profitability of mining projects.

Modelling and assessing the effectiveness of open-pit mining operations represent fundamental abilities within GIS. Leveraging GIS in this domain enables thorough analysis and enhancement of diverse facets within mining operations. Design organisations use digital systems to address various issues related to planning and designing surface mining operations. These digital systems include a variety of tools and features that empower mining engineers to construct and evaluate intricate geological models, evaluate economic viability, and formulate operational strategies for mining activities. One significant benefit of these digital systems is their capability to generate and expand geospatial information support. This assistance streamlines the development of detailed maps and diagrams of mining facilities, including the interactive generation of horizontal plans. Beyond geospatial data, these digital systems can also model and configure complex mine environments using various technical and economic data inputs.

Mining operations in the field can be illustrated using models of dynamic objects influenced by technical processes. Software automation utilises wireframe and block models of the deposit, which include data on the distribution of rock types and mineral composition in the mining area. These models also incorporate a borehole wireframe that offers detailed information about the surface structure (Kotenko & Kynytska, 2023). Based on this, the process of implementing a digital model for open-pit mining and its components is demonstrated through the development and analysis of a digital representation of a mineral deposit using a specialised

integrated system. The core of the information-technological database is a three-dimensional digital model comprising various elements such as topographic surfaces, geological structures, site planning schemes, models of mineral block components, and additional digital attributes specific to open-pit mining (Fig. 1).



**Figure 1.** Three-dimensional models depicting mineral deposits with diverse valuable components

**Source:** developed by the author

The integrated Surpac system enables the creation of digital ore body models incorporating cutting-edge geotechnological advancements, facilitating the identification of efficient volumetric modelling methods for mining objects in open pit environments. Geostatistical

3D modelling involves several essential stages: establishing a database, geometrically modelling the ore body, defining its composition and boundaries, conducting statistical analysis, performing block modelling, and estimating resources. Moreover, Surpac has the capability to be integrated with other software tools within sophisticated mining automation systems, enhancing both the efficiency and precision of production processes.

The geological database serves as a critical component of the Surpac software, forming the foundation for all subsequent calculations and modelling tasks. Surpac utilises a relational database model that establishes connections between various information systems. The geological database comprises several tables, with the interface table (Table 1) and the study table (Table 2) being crucial for optimal functionality. The contiguity tables offer detailed information regarding the positions of drill holes, while the exploration tables provide data on the orientation and direction of these holes. These tables form the foundation for geological modelling, resource estimation, and mine planning. Surpac's geologic database can store a wide range of additional data types, such as assay results, petrologic descriptions, and geophysical data. Furthermore, the software enables users to generate and manage custom tables, ensuring that the geologic database can be customised to meet the specific requirements of each mining project.

**Table 1.** Coordinates of the well entrance

Hole_id	x	y	z	Maximum drilling depth	Path
371	52,498	71,061.21	388.1	40	curved
375	52,502.41	71,084.07	386.12	30.3	curved
382	52,524.07	71,045.16	387.11	35.5	curved

**Source:** developed by the author based on M. Kunytska et al. (2023)

**Table 2.** Coordinates of points in the drilling space

Hole_id	max	Dip	Azimuth
371	40	-90	0
375	30.3	-90	0
382	35.5	-90	0
387	35.2	-90	0
389	34	-90	0
390	34	-90	0
391	34	-90	0

**Source:** developed by the author based on M. Kunytska et al. (2023)

By utilising the "Help" feature, the anticipated geological database permits the generation of reports based on object location using coordinates, borehole depth, azimuth, and drilling angle for either specific boreholes or all available ones. Moreover, it simplifies the extraction of reports concerning tables and database information, offers data on minimum and maximum assigned coordinates, creates lithological columns

in dwf format for chosen wells, and generates reports on intervals surpassing specified content thresholds.

The process of establishing weighted average intervals encompasses two primary phases. Initially, it entails identifying the positions of new intervals neighboring existing ones in the database using drill hole data. Subsequently, the second step entails computing the values of the new intervals acquired through

compositing, thereby ascertaining the metal composition. The outlines of the ore body are delineated through the integration of compositional data gathered from individual drill holes. The wireframe model of the ore body is composed of interconnected polygonal shapes that form polygonal objects, with vertices aligning with existing string points. The combination of these triangles within the wireframe model constitutes the orebody, creating a completely enclosed structure.

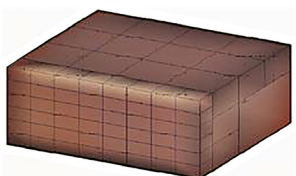
The strategy for designing a wireframe model involves the creation of a triangulation of geological sections covering the longest distances in the longitudinal direction. The triangulation of all segments of these geological sections provides the framework of the orebody (Fig. 2). This geological body structure enables volume calculations considering the working horizon. Surpac streamlines triangulation and inverse distance methods, while grid operations facilitate the computation of mineral reserves.



**Figure 2.** Ore deposit framework

Source: developed by the author

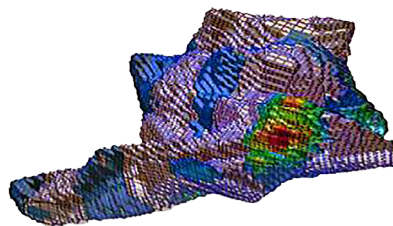
Block modelling involves generating a three-dimensional representation of the site by using a 3D wireframe and partitioning it into fundamental blocks. Subsequently, the block model is imported into GEOVIA MineSched for assessment, where it is used to define the mining zones and allocate mining equipment. The block model is structured as a table, where columns represent site attributes and rows represent individual data entries (Fig. 3).



**Figure 3.** Modelling objects using the block approach

Source: developed by the author

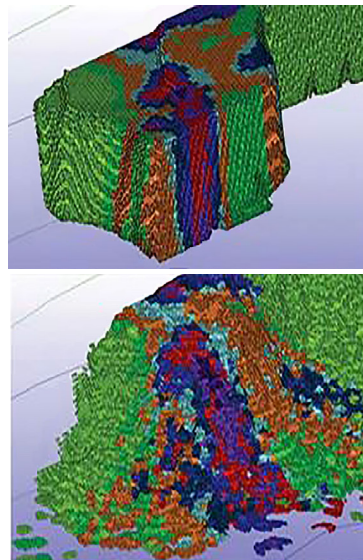
The resultant block model visually illustrates the distribution of valuable components within the orebody through colour coding (Fig. 4). Creating histograms and modelling variograms assists in determining if the orebody should be segmented into homogeneous zones. The variogram considers parameters like thickness, slope, and strike of the orebody to identify spatial variations in heterogeneity.



**Figure 4.** Distribution of valuable components within the orebody

Source: developed by the author

The dynamic aspect of the simulation involves tracking the displacements of fragmented material within the block model caused by explosions that lead to the formation of cracks in the rock mass (Fig. 5). Tracking particle movement offers insights into the dispersion of valuable components during fragmentation, thereby enhancing the reliability of data for addressing production challenges.



**Figure 5.** Modelling of rock destruction by explosives

Source: developed by the author

Therefore, the application of GIS is crucial in the planning, management, and monitoring of surface mining operations, contributing to their efficiency and sustainability. Geographical information systems play a significant role in the modern mining industry, providing extensive opportunities for building three-dimensional models that reflect the geological structures of a deposit and mining facilities. GIS allows building three-dimensional models with high accuracy and detail. With the help of geodetic data and geological information, models can be created that represent the topography, geological formations, mineral locations and mining structures with great accuracy. Three-dimensional models constructed in GIS enable miners to gain deeper insights into the geological composition

of a deposit and strategise and streamline mining operations with greater efficiency. This helps to increase mining productivity and reduce resource consumption. Using three-dimensional models in GIS, it is possible to assess the risks associated with mining operations and take measures to prevent them. This helps to reduce the likelihood of accidents and incidents at mining sites and ensure the safety of employees. GIS enables efficient use of resources at all stages of the mining cycle. This encompasses planning the development of a deposit, controlling the operation of mining facilities, and optimising the processes of restoring the natural environment after mining operations. Three-dimensional models in GIS allow for a better understanding of the geological structure and structure of deposits, which can help identify new mineral deposits and plan further development of the mining industry. In summary, the use of GIS to build three-dimensional models in mining has several advantages that contribute to the efficiency, safety and economic viability of mining operations. They are becoming an important tool for modern mining production, allowing for a deeper understanding of geological processes and optimising mining operations.

According to the study by G. Szujó *et al.* (2023), the introduction of 3D web applications in the mining industry opens great opportunities to improve the productivity and efficiency of mining operations. These web-based applications allow for the creation of dynamic and interactive 3D models of mining facilities, deposits, and structures that can be viewed and analysed from any device with an internet connection. This approach allows miners, engineers, and management to instantly access critical information and make informed decisions about mining operations. These findings are consistent with the points made in the previous section. 3D web applications allow visualisation of the geological structure of deposits, which helps to identify new mineral deposits and plan optimal mining routes. Such applications can also recreate real mining conditions and situations, which allows for staff training in a virtual environment and increases the level of safety while working at the mine. In addition, 3D web applications can be used to monitor the status of equipment and production processes in real time, which allows for timely detection of problems and avoidance of unforeseen failures.

In conformity with a study by J. Yang *et al.* (2024), risk monitoring technologies at mining enterprises are becoming increasingly important in managing safety and improving mining efficiency. The use of advanced technologies, such as geoinformation systems, allows not only tracking potential risks but also managing them effectively. This means that companies can actively use these technologies to analyse and predict risks, which helps to avoid hazards and ensures a safer and more productive environment for workers and equipment. It is worth noting that one of the most promising

technologies is the use of satellite imagery to monitor the condition of mining areas. The high-resolution images that can be obtained through this technology allow for timely detection of changes in the landscape, including landslides, erosion, and other potentially dangerous phenomena. Such data can be used to develop risk management strategies and prevent accidents.

Researchers Ya. Zheng *et al.* (2023) showed in the course of their work that the adaptation of the space industry for three-dimensional modelling of mineral prospects is an innovative approach that provides unique opportunities for studying and assessing geological structures and resources on the Earth's surface. Satellite data, such as high-resolution imagery and radar data, can be used to create three-dimensional models of mountain ranges, ore deposits and other natural formations. It can be agreed that this approach allows mining companies and research organisations to gain a more complete understanding of rock structure and resource distribution. It also helps to optimise exploration and development processes, reducing risks and improving mining efficiency. In addition, three-dimensional models based on satellite data can be used to predict potential finds and determine the best locations for drilling and subsequent production.

As noted by Yu. Cao *et al.* (2023), modelling and dynamic analysis of an integrated vertical transport system for deep-sea mining in three dimensions is an important aspect of the modern mining industry. This approach allows engineers and researchers to more effectively plan and manage mining operations at great depths, where traditional methods are not effective enough. By analysing the results and conclusions obtained, such models allow considering various aspects of production, including the geological structure of deposits, physical properties of rocks, pressure, and temperature conditions at depth, as well as technical parameters of the equipment and infrastructure used. Dynamic analysis allows predicting the behaviour of the system in different conditions and optimising its operation for maximum productivity and safety. This is especially relevant for mining in deepwater fields, where there is a risk of various man-made and environmental problems.

Researcher H. Fan *et al.* (2021) determined that a new model for three-dimensional deformation extraction using single-track interferometric radar sensing (InSAR) opens opportunities for researchers to more accurately monitor and analyse deformations resulting from mining operations. Single-track InSAR is based on the principle of radar interferometry and allows measuring changes in the distance between the satellite and the Earth's surface with high accuracy. InSAR works by measuring the interference between signals reflected from the Earth's surface, which are received at different times. This technique makes it possible to detect changes in the relief and movements of the Earth's surface

with high accuracy. The advantages of InSAR include high resolution, the ability to monitor large areas and high sensitivity to micrometric changes. Compared to other methods, such as GPS or total station, InSAR can be more efficient and convenient for measuring changes in the terrain over a large area. InSAR technology has a wide range of applications, including detecting deformations in oil fields, studying tectonic movements, monitoring volcanic activity, analysing geological processes, and more. This makes it an indispensable technique for many research and practical applications in the field of land management and geoinformatics. In addition, this model provides information on the characteristics of subsidence in mining operations, such as the rate of movement of rock masses, the extent of deformation and its spatial distribution. Three-dimensional deformation extraction allows for a more complete and accurate assessment of the impact of mining operations on the environment and infrastructure, such as roads, buildings, and communications. This helps to reduce the risk of accidents and improve the planning and management of mining projects.

### ● Conclusions

The study found that geographic information systems are extremely useful and effective tools for building three-dimensional models in mining. They made it possible to accurately visualise mining operations before they begin, which helped analyse potential risks and develop optimal mine exploitation strategies. This has reduced the likelihood of accidents and incidents at mining operations and helped to improve their efficiency and safety. Attempts were made to automate the detection of landslide hazard zones using the latest computer technology.

Consequently, the integrated Surpac system enables the generation of digital ore deposit models incorporating advanced geotechnologies, streamlines

the identification of effective volumetric modelling methods for open pit mining objects, and enhances overall process efficiency and accuracy through integration with other software tools. In addition, GEOVIA MineSched's block modelling facilitates efficient analysis and allocation of mining equipment based on a three-dimensional representation of the object. One of the primary advantages of GIS in mining is its capability to generate intricate 3D models that accurately depict complex geological structures and mineral locations. This allows miners to understand the minefield and optimise mining processes to achieve maximum productivity and efficiency. Additionally, an important advantage of using GIS is its ability to integrate with other technologies, such as satellite imagery and automated control systems, which allows for a more complete and accurate view of mining processes and their management with great precision.

Overall, the study results confirmed the importance and prospects of using GIS in mining. These technologies have the potential to improve the safety, efficiency, and profitability of mining enterprises, making them an integral part of modern mining production. It is important to conduct additional research on the impact of the development of new technologies on the cost and availability of GIS for mining companies. Estimating costs and studying trends in this area will help to understand how technological progress can affect the cost of implementing and operating GIS in mining, as well as their overall accessibility for mining companies of different sizes and levels of technological development.

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### ● Conflict of Interest

None.

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## **Можливості та переваги ГІС для побудови трьохвимірних моделей у гірництві**

● **Анотація.** Актуальність проведення дослідження зумовлена необхідністю оптимізації видобутку корисних копалин, моніторингу та управління ризиками, що вимагає швидкого впровадження передових технологій для забезпечення сталого розвитку гірничої промисловості. Метою даного дослідження був аналіз нового підходу до використання географічних інформаційних систем. Серед використаних методів слід зазначити метод спостереження, метод опису, метод порівняння, метод моделювання та інші. У рамках дослідження був проведений аналіз нового підходу до використання географічних інформаційних систем у гірництві для побудови тривимірних моделей. Шляхом впровадження цієї методики в гірничу практику в Україні досягнуті значні позитивні зміни: зменшено ризики надзвичайних ситуацій, оптимізовано процеси видобутку, підвищено загальну продуктивність. Також виявлено, що використання географічних інформаційних систем дозволяє збільшити точність планування гірничих робіт і знизити витрати на їх виконання. Порівняно з традиційними методами моделювання, новий підхід заснований на географічній інформаційній системі, і дозволяє отримувати більш точні та надійні дані про геологічні структури та розподіл корисних копалин. У результаті дослідження було підтверджено, що впровадження таких технологій може суттєво підвищити конкурентоспроможність гірничих підприємств, забезпечуючи їм інструменти для більш точного прогнозування та управління процесами видобутку. Практичне значення цього дослідження полягає в установленні ефективного методу застосування географічних інформаційних систем для побудови тривимірних моделей у гірництві, що відкриває нові можливості для підвищення ефективності та безпеки гірничих операцій, зокрема в Україні, сприяючи сталому розвитку галузі та економіки країни

● **Ключові слова:** розвідувальна мережа; технології; видобуток; копалини; комп'ютерне моделювання; карти