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# INDUSTRIAL ENGINEERING APPROACHES FOR MINERAL RESOURCE MANAGEMENT: INTEGRATING UAV AND GNSS TECHNOLOGIES IN MINING OPERATIONS

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***Abstract.*** *The mining industry is currently undergoing a significant digital transformation, driven by the integration of advanced geomatic technologies and modern industrial engineering approaches. This paper investigates the use of Unmanned Aerial Vehicles (UAVs) equipped with Real-Time Kinematic (RTK) systems and Global Navigation Satellite Systems (GNSS) for the assessment and management of mineral resources in surface mining operations. The proposed approach combines aerial photogrammetry and ground-based geodetic measurements to support efficient resource evaluation, operational planning, and sustainable exploitation practices. The study was conducted within the Bodrogu Nou mining perimeter, Romania, where UAV data acquisition and GNSS measurements were integrated to generate orthophotoplans, digital elevation models, and topographic documentation required for mining management. The implemented workflow included mission planning, establishment of ground control points, GNSS measurements, aerial data acquisition, and photogrammetric processing using specialized software. The obtained results demonstrate that UAV and GNSS technologies significantly improve data accuracy, reduce survey time, and provide high-resolution spatial information required for volume calculations, exploitation planning, and environmental monitoring. The generated digital models enabled the calculation of extraction volumes and supported the subdivision of mining activities into operational stages. From an industrial engineering perspective, the integration of these technologies contributes to the optimization of surveying procsses, improves operational efficiency, and supports data-driven decision-making throughout the mining lifecycle. The proposed methodology offers a reliable and cost-effective solution for modern mine management, facilitating the continuous monitoring of extraction activities while promoting sustainable resource utilization and supporting the digital transformation of the mining industry.*

***Keywords***: *UAV, GNSS, industrial engineering, photogrammetry, process optimization, resource management, sustainable mining.*

## INTRODUCTION

The mining industry is currently experiencing a significant transformation generated by the rapid development of digital technologies and modern engineering solutions. Increasing demands regarding resource efficiency, environmental protection, operational safety, and sustainable exploitation require the implementation of advanced monitoring and management systems. In this context, industrial engineering principles, combined with modern geomatic technologies, play an increasingly important role in optimizing mining operations and supporting decision-making processes.

Surface mining activities require accurate spatial information regarding the geometry of exploitation areas, material volumes, topographic conditions, and environmental changes. Traditional surveying methods, although reliable, often involve considerable fieldwork, long processing times, and increased operational costs. Recent technological advances have introduced new opportunities for improving data acquisition and processing, particularly through the use of Unmanned Aerial Vehicles (UAVs) and Global Navigation Satellite Systems (GNSS).

UAV technology has become one of the most important innovations in geospatial data acquisition. Equipped with high-resolution cameras and Real-Time Kinematic (RTK) positioning systems, drones are capable of collecting large amounts of spatial information rapidly and accurately. The resulting aerial imagery can be processed to generate orthophotoplans, digital elevation models, three-dimensional models, and various thematic maps required in mining applications. These products provide essential information for resource assessment, extraction planning, environmental monitoring, and operational management.

At the same time, GNSS technologies provide centimetre-level positioning accuracy necessary for establishing ground control points and georeferencing aerial data. The integration of UAV and GNSS measurements ensures high-quality spatial datasets that can support both engineering calculations and mining management activities. Modern software solutions for photogrammetric processing and geospatial analysis further contribute to the automation and optimization of these workflows.

From the perspective of industrial engineering, the implementation of digital surveying technologies contributes to process optimization, operational efficiency, quality control, and risk reduction. The concept of digital transformation, often associated with Industry 4.0, promotes the use of intelligent systems, automation, and data-driven decision-making processes. Mining companies increasingly adopt these technologies to improve productivity, reduce costs, minimize environmental impacts, and enhance worker safety.

The sustainable exploitation of mineral resources represents another major challenge for the mining industry. Accurate monitoring of extraction activities, volume calculations, and environmental changes is essential for ensuring compliance with regulations and promoting responsible resource management. Modern geomatic technologies allow continuous monitoring of mining areas and provide valuable information for environmental assessment and rehabilitation activities.

The present study investigates the integration of UAV photogrammetry and GNSS measurements for mineral resource management within the Bodrogu Nou exploitation perimeter, Arad County, Romania. The research focuses on the acquisition, processing, and analysis of spatial data required for the evaluation of exploitation volumes and the organization of mining activities. The results demonstrate the significant potential of modern geomatic technologies as valuable tools for industrial engineering applications and the digital transformation of mining operations.

## MATERIAL AND METHODS

The study was conducted within the **Bodrogu Nou mining perimeter**, located in Arad County, western Romania, an area characterized by significant deposits of sand and gravel that are intensively exploited for construction and infrastructure development. The mining perimeter covers approximately **0.022 km²** and has been under continuous exploitation since **1997**, providing a representative environment for evaluating the application of modern geomatic technologies in surface mining operations.

The site was selected due to its active extraction activities, well-defined exploitation boundaries, and the continuous need for accurate topographic monitoring to support operational planning and resource management. As extraction progresses, frequent updates of the topographic documentation are required to determine the current configuration of the

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quarry, monitor terrain changes, calculate extraction volumes, and ensure compliance with mining regulations.

According to the official mining documentation, the maximum authorized exploitation depth within the study area is **+95.5 m**, while all extraction activities are carried out within the limits established by the approved exploitation plan. Accurate monitoring of the mining perimeter is therefore essential for optimizing production processes, controlling extracted quantities, and minimizing environmental impacts associated with mining activities.

The Bodrogu Nou quarry represents a suitable case study for demonstrating the advantages of integrating **Unmanned Aerial Vehicle (UAV) photogrammetry** with **Global Navigation Satellite System (GNSS)** surveying techniques. The combination of these technologies enables the rapid acquisition of high-resolution spatial data, the generation of accurate digital terrain models, and the calculation of excavation volumes with centimeter-level accuracy. Furthermore, the digital datasets produced during this study support efficient decision-making, improve operational planning, and contribute to the implementation of modern industrial engineering principles within mining resource management.

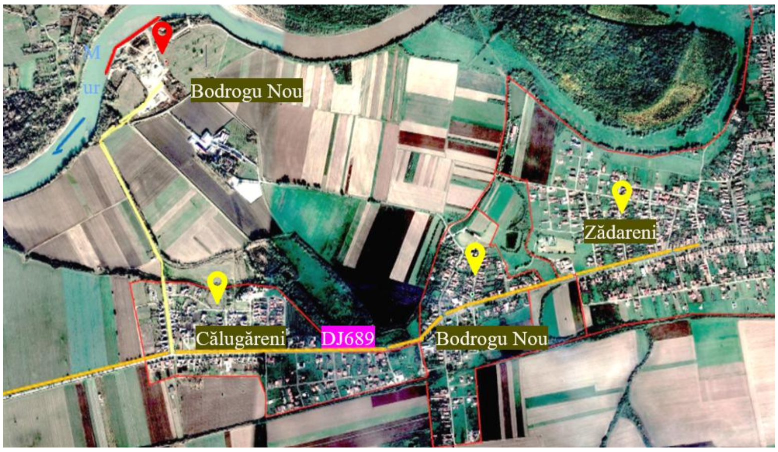

Figure 1. Location of the Bodrogu Nou mining perimeter and orthophotomap of the study area.

The geospatial data acquisition process involved both aerial and terrestrial surveying equipment. The aerial surveys were performed using a DJI Mavic 3 RTK unmanned aerial vehicle equipped with a high-resolution camera and RTK positioning capabilities. The terrestrial measurements were conducted using a HI-TARGET V30 GNSS receiver operating in RTK mode.


Figure 2. DJI Mavic 3 RTK UAV used during data acquisition.

The main equipment used during the study includes:

- DJI Mavic 3 RTK UAV;
- HI-TARGET V30 GNSS receiver;
- Ground Control Points (GCPs);
- DJI Pilot 2 software;
- Agisoft Metashape software;
- TopoLT software.

The terrestrial control network was established using a HI-TARGET V30 GNSS receiver operating in Real-Time Kinematic (RTK) mode. The measured Ground Control Points were used to improve image georeferencing accuracy and validate the generated spatial products.

Figure 3. HI-TARGET V30 GNSS receiver and Ground Control Point used during the survey.

Prior to image acquisition, the mining perimeter was inspected and the flight mission was designed using DJI Pilot 2 software.

The flight plan included:

1. flight altitude;
2. image overlap (approximately 70%);
3. flight speed;
4. camera parameters;
5. flight boundary.

The autonomous UAV mission enabled rapid image acquisition while maintaining high spatial accuracy.

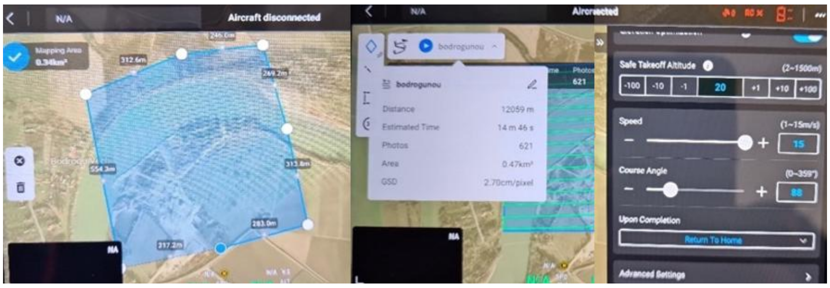


Figure 4. Flight mission planning using DJI Pilot 2 software.

After completing the UAV mission, all acquired images were transferred to the processing workstation.

Photogrammetric reconstruction was performed using Agisoft Metashape Professional, following the standard workflow:

1. image alignment;
2. sparse point cloud generation;
3. dense point cloud generation;
4. Digital Elevation Model generation;
5. orthophotomap generation;
6. export of geospatial products.

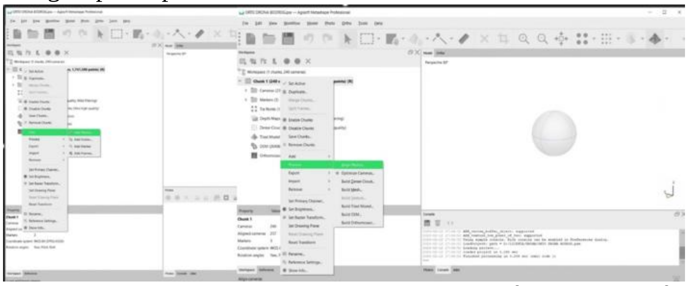

Figure 5. Image alignment and photogrammetric processing performed in Agisoft Metashape.

## RESULTS AND DISCUSSIONS

### *Establishment of the Mining Perimeter*

The first stage of the study consisted of defining the boundaries of the Bodrogu Nou mining perimeter and establishing the reference framework required for the subsequent surveying activities. The perimeter was delineated using RTK GNSS measurements, ensuring accurate positioning of the exploitation limits within the national Stereographic 1970 coordinate system.

The resulting geometric configuration represents the basis for all subsequent engineering analyses, including orthophotomap generation, digital terrain modeling, and volume estimation. The accurate definition of the mining boundary minimizes positioning errors and provides reliable spatial information for operational planning.

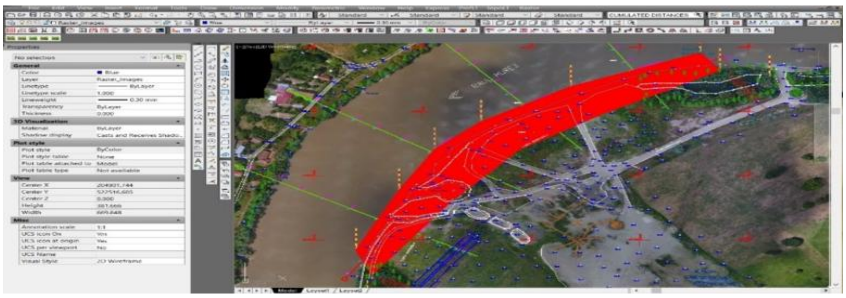

Figure 6. Geometric representation of the Bodrogu Nou mining perimeter

The integration of GNSS observations into the digital workflow contributes to improving surveying efficiency while reducing field measurement time.

***Digital Terrain Modeling and Spatial Analysis***

Following photogrammetric processing, a high-resolution Digital Elevation Model (DEM) and orthophotomap were generated from the UAV imagery. These products provide an accurate representation of the terrain morphology and constitute the primary datasets used for engineering analysis.

The DEM enabled the identification of terrain irregularities, excavation fronts, and elevation differences throughout the exploitation area. Furthermore, the generated orthophotomap facilitated the precise delineation of operational sectors and the subdivision of the mining perimeter into extraction stages.

Compared with traditional topographic surveys, the UAV-derived datasets provide significantly higher spatial density while considerably reducing fieldwork duration. This digital approach supports continuous monitoring of mining activities and improves decision-making during operational planning.

The generated geospatial products also serve as valuable inputs for Geographic Information Systems (GIS), Computer-Aided Design (CAD), and mine management platforms.

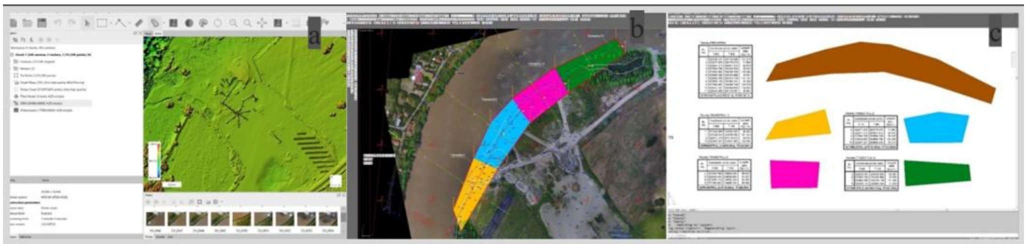


Figure 7. Digital Elevation Model (DEM), updated exploitation map, and coordinate inventory generated from UAV data.

***Longitudinal and Cross-Sectional Profile Analysis***

Based on the generated digital terrain model, one longitudinal profile and four transverse profiles were extracted across the mining perimeter. These profiles provide detailed information regarding terrain morphology and excavation geometry.

Cross-sectional analysis represents one of the most widely used engineering methods for estimating excavation volumes in surface mining. The generated profiles allow the identification of slope variations, excavation depth, and operational limits established within the exploitation plan.

The obtained sections also facilitate the planning of future extraction activities by providing accurate geometric information regarding the remaining mineral resources.

In addition, the analysis of these profiles enables the detection of potential irregularities in the excavation process, such as uneven slopes or deviations from the designed extraction geometry. This contributes to improving operational safety and ensuring compliance with technical specifications.

Moreover, the extracted profiles can be used as reference data for monitoring temporal changes in the terrain, allowing engineers to assess the evolution of the mining front over time. Such monitoring is essential for optimizing extraction strategies and minimizing environmental impact.

The integration of profile analysis within the digital workflow enhances the overall efficiency of the surveying process and supports data-driven decision-making in mining operations.

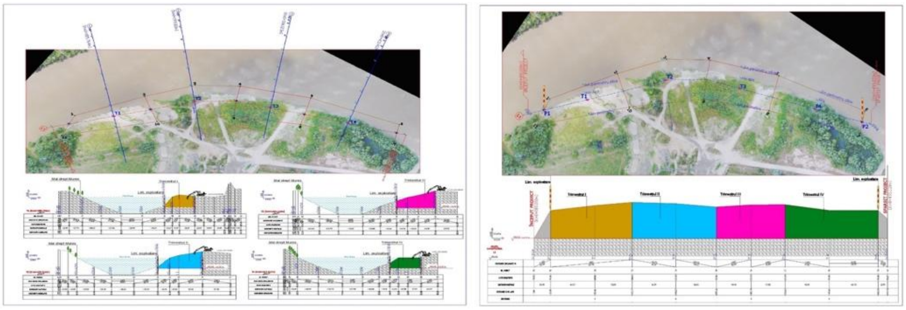

Figure 8. Longitudinal and transverse profiles extracted from the Digital Terrain Model.

***Volume Estimation***

The calculated cross-sectional areas were combined with the applicable distances between adjacent sections to estimate the exploitable mineral volume. The obtained results indicate a total calculated excavation volume of approximately **89,022 m³**, corresponding to an estimated **55,639 tonnes** of exploitable material.

The highest extraction potential was identified within Quarter II, while the remaining operational sectors presented relatively balanced excavation capacities. Such information is essential for production scheduling, equipment allocation, and long-term resource management. The implemented methodology allows rapid updating of volume calculations whenever new UAV surveys are performed, providing mining operators with accurate information for operational decision-making.

The results demonstrate that integrating UAV photogrammetry with RTK GNSS surveying provides an efficient solution for modern mining operations. The proposed methodology significantly reduces field surveying time while improving spatial accuracy and data availability. From an industrial engineering perspective, the developed workflow contributes to process optimization by automating data acquisition, reducing manual measurements, and accelerating engineering analyses. The generated digital products support resource planning, production management, environmental monitoring, and quality control throughout the mining process. Furthermore, the integration of UAV-derived datasets into CAD and GIS environments enables continuous updating of mining documentation and facilitates digital transformation within the mining industry. Compared with conventional surveying techniques, the proposed methodology offers greater operational flexibility, higher spatial resolution, and improved support for strategic decision-making.

These findings confirm that UAV and GNSS technologies have become essential components of modern industrial engineering applications in surface mining, supporting sustainable resource exploitation while increasing operational efficiency and reducing project implementation time.

## CONCLUSIONS

This study demonstrates the effectiveness of integrating UAV photogrammetry and RTK GNSS surveying for the assessment and management of mineral resources in surface mining operations. The proposed methodology enables the rapid acquisition of high-resolution geospatial data, providing reliable information for topographic documentation, digital terrain modeling, and excavation volume estimation.

The case study conducted within the Bodrogu Nou mining perimeter confirmed that the combination of aerial and terrestrial surveying techniques significantly improves the efficiency of data collection while maintaining centimeter-level positional accuracy. The generated orthophotoplans, Digital Elevation Models (DEMs), and topographic profiles provided the spatial information required for operational planning and monitoring of extraction activities. From an industrial engineering perspective, the implemented digital workflow contributes to process optimization by reducing field surveying time, minimizing manual measurements, and supporting data-driven decision-making. The integration of UAV technology with GNSS positioning and specialized photogrammetric software enhances operational efficiency, facilitates production planning, and improves the management of mining resources throughout the exploitation process.

Furthermore, the use of modern geomatic technologies supports sustainable mining practices by enabling continuous environmental monitoring, accurate resource evaluation, and periodic updating of mining documentation. The digital products generated during the study can be directly integrated into CAD and GIS environments, providing valuable information for engineering analysis and long-term mine management.

Future research will focus on integrating artificial intelligence algorithms, automated feature extraction, and digital twin technologies into the UAV–GNSS workflow in order to further improve monitoring capabilities, predictive analysis, and decision support systems for smart mining applications.

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