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Monitoring the share of barren rock in extracted run-of-mine using digital deposit model and mine structural model – case study

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Abstract. This paper explores the utilization of mine structural models in optimizing operations at the "Pniówek" coal mine, focusing specifically on monthly data regarding the proportion of barren rock extracted alongside coal and its origins. Highlighting the significance of monitoring barren rock extraction in underground mining, with "Pniówek" serving as a case study, the article delves into the adverse effects of excessive barren rock in the Coal Mechanical Processing Plant feed and its consequent impact on daily plant performance. Furthermore, it elucidates the journey of excavated material from longwall extraction through processing plant operations to the final products. Subsequently, the paper presents a detailed analysis of coal yield, its composition, and a graphical representation of gangue proportions using Gantt charts. Additionally, it provides insights into forecasting gangue proportions in extraction, along with methods for interpreting and leveraging the obtained information for further operational optimization.

1 Introduction

Monitoring the proportion of barren rock within extracted run-of-mine material constitutes a complex process reliant on cutting-edge technological tools [1]. These tools, exemplified by digital deposit models and mine structural models, signify significant advancements in mining operations [2]. Digital deposit models serve as the cornerstone of this process, harnessing geological data, spatial analysis, and computational algorithms to construct intricate representations of the ore body and its surrounding geological formations [3]. By meticulously delineating the geological characteristics of the deposit, encompassing variations in mineral composition, rock density, and structural features, these models offer invaluable insights into the distribution and prevalence of barren rock within the extracted material [4 – 6].

Conversely, mine structural models assume a crucial role in comprehending the structural integrity and layout of the mine [4 – 7]. Leveraging geological surveys, geophysical data, and engineering principles, these models meticulously outline the geological structures, faults, fractures, and other structural complexities inherent within the mine [8, 9]. Through a comprehensive assessment of the geological and structural attributes, these models furnish

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critical information concerning the spatial distribution and orientation of distinct geological formations [10]. Such insights directly influence the extraction process and the composition of the extracted final material [11].

By amalgamating data from digital deposit models and mine structural models, mining operations can proficiently monitor the proportion of barren rock within the extracted run-of-mine material [12, 13]. This integrated approach facilitates real-time analysis and visualization of the geological and structural characteristics of the deposit, empowering mining engineers and geologists to make well-informed decisions pertaining to extraction methodologies, resource allocation, and waste management strategies [14 – 16]. Ultimately, through the adept utilization of advanced technological tools for monitoring barren rock content [17]. Mining companies can optimize their operations, curtail waste, and enhance resource recovery, thereby fostering heightened efficiency, productivity, and sustainability within the mining industry [18].

Plan and schedule of mining activities is a crucial part of Deposit Development Project, a document required by polish law to conduct any mining activities [19]. Even though this document is prepared for many years in advance, factors like limited recognition of a deposit, changes in mining costs, technical capabilities or natural hazards force engineers to change mining schedules on a daily basis [20, 21]. In addition, mining investment requires large capital expenditures which take several years before allowing for positive cash flow [22, 23]. Because of that effective mining investment requires extensive recognition of deposit as well as monitoring of all mining activities, and should be preceded by a multivariate scenario analysis phase [24].

Methods of quantitative optimization of mining process have been researched since half of XX century. First attempts were conducted using graph analysis and canonical network analysis [25, 26]. Network algorithms have been proposed as a support for underground mine planning [27, 28]. Methods of optimizing mine workings are well-known in open-pit mining, while in underground mining these topic are much less popular due to this mining method's natural restrictions requiring use of multiple model constraints [29, 30]. Those methods have been, however, developing rapidly in recent years due to increasing access to computing power [31]. In this field three main fields of research can be established:

– Optimizing mine scheduling through heuristic algorithm or mixed-integer programming [32 – 34];
– Optimizing stope layout through heuristic algorithm [29, 35, 36];
– Optimizing access and development plan using heuristic algorithm [25, 28, 37].

Meanwhile there is limited research on influence of barren rock extracted along with the resources on the schedule and methods of reducing its negative impact. This paper aims to shed a light on the importance of including barren rock forecasting in planning the mining exploitation.

1.1 "Pniówek" Mine – Basic parameters

"Pniówek" is a mine with two mining areas with a total area of almost 60 km^2, in which the total length of active corridor workings is about 120 km. The mine is accessed by 5 shafts, in which approximately 6 longwall faces are simultaneously excavated and about 20 corridor faces at a time are mined. The mine constructs about 20 km of corridor excavations each year and employs more than 7.5 thousand workers. More than 50 km of overhead rail routes and about 25 km of conveyor belt routes are installed in "Pniówek".

1.2 Digital deposit model and mine structural model

The structural model of the mine works on data from the geomodel. The geomodel consists of 30 modelled seams, which include structural parameters marking the location and geometry of deposit and 17 quality parameters describing chemical properties of seam coal, with emphasis on its coking properties. The structural model (Fig. 1), by depicting planned mining of the modelled seams, provides information on how much, when and of what quality coal the mine will bring to the Earth's surface. In the model there are developed schedules and projects, which can cover even the entire mining period. For the "Pniówek" mine, this means more than 200 longwalls by 2050. The report on coal yield and the share of barren rock in mining has become an integral part of the production schedule and has been in function since October 2020.

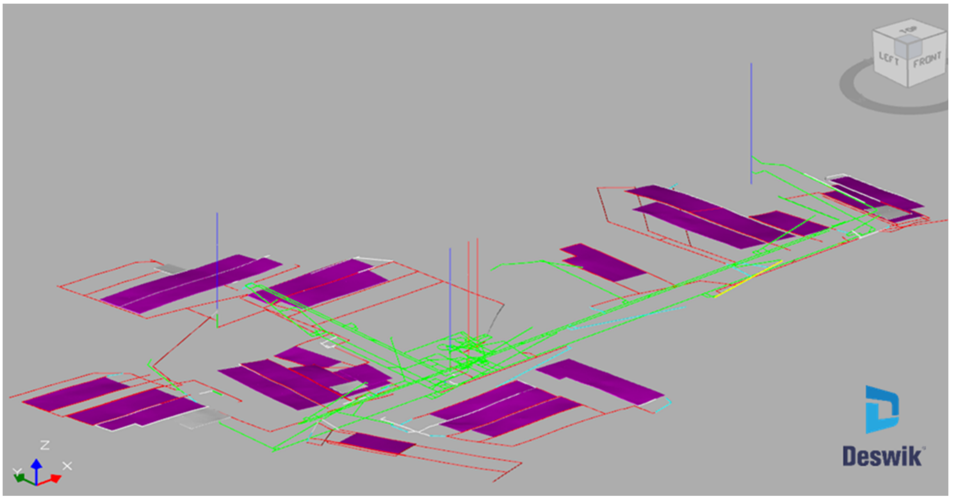

Fig. 1. View of corridor workings and longwalls planned for mining in the "Pniówek" mine (short-term horizon) in one of developed variants.

1.3 Route of excavated material in the process line

After shearing from the longwall face, excavated material is transported by conveyors to 2 underground tanks with a capacity of 2.000 Mg each, then it is pulled by skip to the surface, where it goes to the coal preparation station. There it is crushed on screens, and the largest rock fragments are removed from it on conveyor belts. From there material goes to 4 raw coal bins with a capacity of 1.250 Mg each and then goes through the washing and flotation processes. In order for these processes to run smoothly and not be disturbed, it must be ensured that the designed daily capacity of the Coal Handling and Preparation Plant (pol.: Zakład Przeróbki Mechanicznej Węgla*) is not exceeded.*

1.4 Waste rock – negative impacts on the mine

The Coal Handling and Preparation Plant (ZPMW) of the "Pniówek" mine was designed to handle up to 30.000 Mg of excavated material gross per day, and if the share of waste rock in the feed is greater than 50%, the plant's capacity is reduced to 28.000 tons of excavated material (gross) per day. The main issues with the proportion of waste rock in the feed being too high are: first, logistical problems involving rail transportation of stone to the stockpile and transport inside the plant by conveyor belts, and second, problems of flotation during sedimentation and filtration. The excessive amount of stone in the feed going to the ZPMW causes excessive overloading of the transport system and the water-sludge (flotation) circuit. Those logistic and processing processes would require major investments to accelerate – transport takes place in a fixed time, and the settling of stone in the process of sedimentation and dewatering of flotation waste has its fixed duration.

2 Methodology

Monitoring the share of barren rock in extracted run-of-mine (ROM) using a digital deposit model and mine structural model involves several interrelated steps. Initially, comprehensive data collection is paramount. This entails gathering geological data on the deposit, encompassing lithology, mineralization, and structural information. Concurrently, details concerning the mine's structural layout, such as orebody geometry, faults, and structural controls, need to be collated.

Following data collection, the creation of a digital deposit model is pivotal. Utilizing geological modeling software, this model should intricately portray the geological features of the deposit, including ore zones, barren rock, and structural elements. Integration of data from drilling, sampling, and geological mapping ensures the model's accuracy and fidelity to the deposit's actual characteristics.

Simultaneously, the development of a mine structural model is undertaken using specialized mining software. This model should accurately reflect the physical layout of the mine, encompassing production areas, haulage routes, and excavation methods. Incorporating data on mining methodologies, equipment utilization, and operational constraints ensures the model's alignment with real-world mining practices.

The integration of the digital deposit model with the mine structural model marks a crucial juncture. This amalgamation creates a unified framework where the geological features depicted in the digital deposit model seamlessly align with the mining areas and activities represented in the mine structural model.

Subsequently, employing this integrated model facilitates simulation and analysis of mining operations and ROM extraction. By scrutinizing the output, insights into the distribution of barren rock within the extracted ROM can be gleaned. This analysis enables the identification of areas characterized by high barren rock content and potential sources of dilution.

Continual monitoring of mining operations and ROM composition ensues, leveraging data from production reports, sampling endeavours, and grade control mechanisms. A comparative analysis between the actual ROM composition and the predictions derived from the digital model guides adjustments to the model parameters, ensuring ongoing refinement to enhance accuracy and predictive capability.

In essence, this iterative process of data integration, simulation, analysis, and adjustment forms a robust methodology for monitoring the share of barren rock in extracted run-of-mine, ultimately optimizing resource utilization and operational efficiency within the mining context. The main sources of barren rock involved in mining are mined coal seams with increased contamination, multiple coal seams mined together (due to the small distance between the seams) and coal seams mined together with accompanying layers. Additional source are development excavations – access workings, which are most often rock excavations, as well as corridor roadways drilled in low seams, intended for mining by plough technology. In addition, but to a lesser extent, rock is excavated during the rebuilding of workings.

2.1 Sources of stone – contamination of seams

The contamination of the coal seam directly affects the waste rock content of the ore. The figures below (Fig. 2) show the difference between the extracted rock mass at similar mining volumes in each month in two different seams: in a seam with increased contamination (coal yield of 66%) and in a seam with low contamination (coal yield of 88%). In both cases, the longwall gates marked in yellow fully encompass the modelled coal seams and no rock waste is sheared from layers over or under the seam.

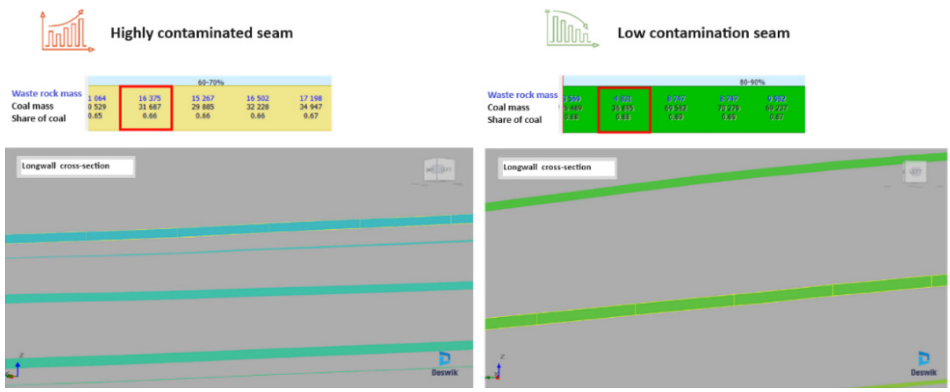

Fig. 2. Sources of waste rock – contamination of seams.

2.2 Waste rock sources – rocks between seams

Another very important source of waste rock is the joint exploitation of two seams located near each other or the exploitation of the main seam together with the accompanying layer (all grey is waste rock) – here the amount of rock contained in the established gate of a given longwall is shown in model explicitly (marked in yellow). The following illustrations (Fig. 3) show how a longwall gate covers two seams with a separating layer of rock that must be mined along with the coal.

Fig. 3. Sources of waste rock – between coal layers.

2.3 Sources of waste rock – corridor excavations

Development workings are also a source of waste rock: for example, access workings that only pass through successive coal seams from occasionally, as well as workings in narrow seams that are part of the cut for longwalls equipped with a plough. The figures below (Fig. 4) illustrate these sources of waste rock.

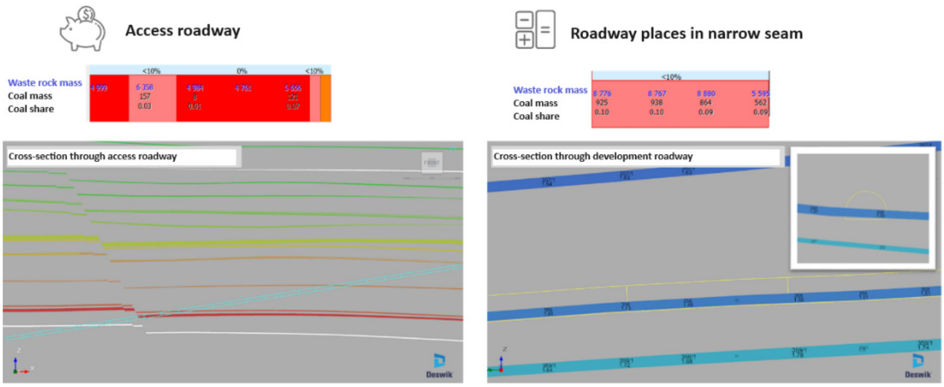

Fig. 4. Sources of waste rock – corridor excavations.

2.4 Interpretation of geomodel in mine structural model

The seam solid contained in the geomodel consists of parts containing structural and qualitative parameters. When coding the seam for the structural model, the structural and qualitative parameters are averaged, i.e. the coal and rock layers of the structural model are modelled as averaged values of seam thickness and parting share. The figure below (Fig. 5) shows the correspondence of the structural parameters contained in the geomodel with the values placed on the numerical map – the same thickness of pure coal of 2.63 m is obtained on both sides.

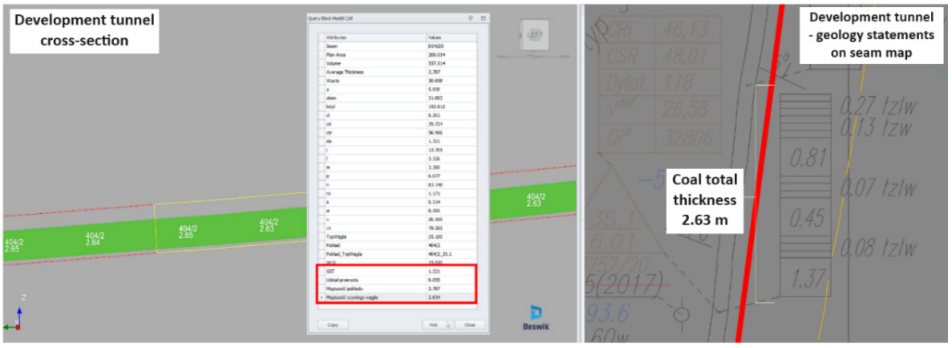

Fig. 5. Comparison of structural parameters of the geomodel with statements on the mine map.

To be more precise: *the thickness of the seam* amounts to *coal + partings thickness* while *the proportion of partings* tells us how much of the seam's height is not the resource (coal) – it determines the sum of impurities and is expressed as a percentage of rock in the solid. The figure above presents the share of partings, which is 5.5% in this task.

3 Results and discussions

In addition to basic production information, the report also contains information on coal yield – with respect to longwalls only and in relation to total output. We can see what the weight of excavated material is in each month, which includes the weight of clean coal and rock. The data is also presented in terms of daily output, and there is a formula (Fig. 6) indicating a reduction in the output of the Coal Handling and Preparation Plant if the proportion of waste rock in the feed exceeds 50% – when this happens the colour of the text automatically changes to red, and this is a clear signal to check what is the cause of the increased proportion of waste rock in coal output in a given month.

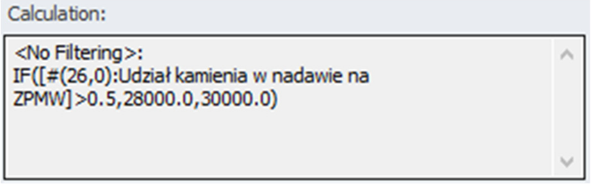

Fig. 6. Formula that determines the limit of feed to ZPMW.

3.1 Coal yield report – Gantt chart

The Gantt chart view allows to read directly on production tasks the amount of coal and rock mined and the percentage of coal yield. These data are summed up in each month and presented in the cells of the report presented earlier. The figures below (Figs. 7 and 8) show coal yield separately for the corridor pits and the production pits.

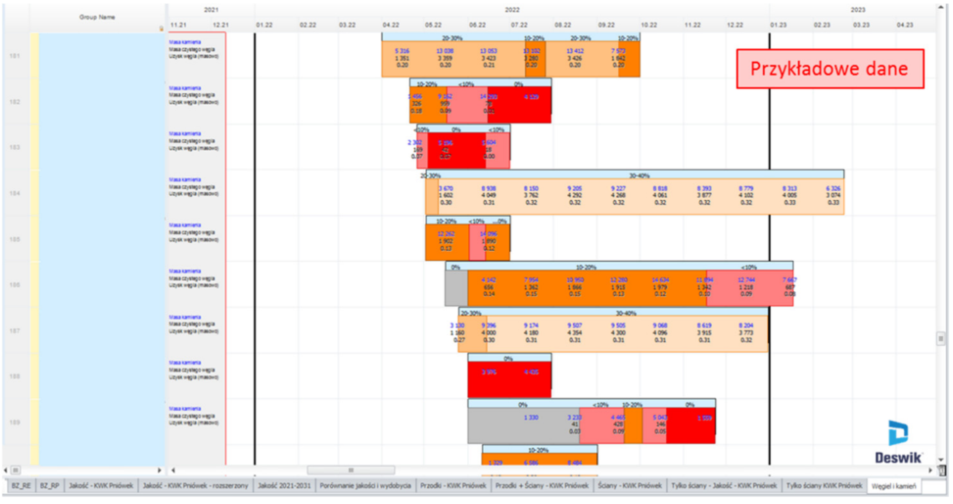

Fig. 7. Coal yield report – Gantt chart (corridor excavation).

The implementation of new reporting capabilities has significantly enhanced the operational efficiency of relevant mine services. These capabilities offer precise and relevant information, particularly considering the constraints posed by the Coal Processing Plant's capacity to receive run-of-mine material. With these advancements, pertinent data is automatically generated every time the schedule undergoes an update. This seamless integration of reporting functionalities ensures that key stakeholders are equipped with up-to-date insights into the operational status and resource utilization within the coal processing workflow (Fig. 9).

Fig. 8. Coal yield report – Gantt chart (mining excavations).

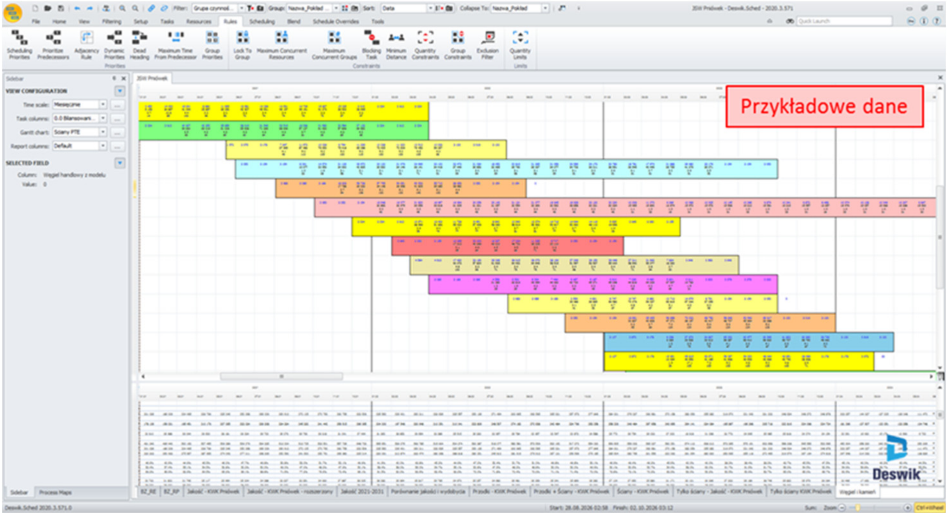

Fig. 9. Coal yield report – Gantt chart view and report fields.

By leveraging this information, decision-makers can proactively address any bottlenecks or inefficiencies, thereby optimizing the overall productivity and performance of the processing plant. Moreover, the availability of accurate and timely reporting facilitates better coordination and planning across various mine services, fostering a more streamlined and synchronized operation. Ultimately, these enhanced reporting capabilities play a pivotal role in driving operational excellence and maximizing the value derived from the coal processing operations.

Thanks to this model it is possible to monitor the composition of the feed transferred to the Coal Processing Plant on an ongoing basis, which translates into better control in planning, both operational and strategic, and when the coal yield report identifies a significant overrun of the Plant's capacity, the mining schedule is subject to a thorough analysis and, if necessary, is redesigned.

3.2 Discussion of results

The integration of advanced reporting capabilities into coal mining operations has ushered in a new era of operational efficiency and control. Beyond providing fundamental production data, these reports offer nuanced insights into coal yield, specifically highlighting its correlation with longwall mining and total output. By meticulously documenting the weight of excavated material, encompassing both clean coal and rock, on a monthly and daily basis, these reports enable stakeholders to monitor feed composition to the Coal Processing Plant meticulously.

Moreover, the inclusion of a formula indicating a reduction in the output of the Coal Handling and Preparation Plant when the proportion of waste rock in the feed exceeds 50% adds a layer of proactive management. This automated color change to red in the text serves as a clear signal, prompting stakeholders to investigate the cause of the increased waste rock content in coal output for a given month. The visual representation offered by the Gantt chart view enhances accessibility and readability of production tasks, allowing stakeholders to directly observe the amount of coal and rock mined and the percentage of coal yield. These data are aggregated monthly and presented comprehensively, offering a holistic view of coal yield, whether from corridor pits or production pits.

The implementation of these reporting capabilities has revolutionized operational oversight within relevant mine services. By automatically generating pertinent data with each schedule update, stakeholders are equipped with real-time insights into operational status and resource utilization. This seamless integration ensures timely decision-making and proactive management of bottlenecks or inefficiencies, thereby optimizing overall productivity and performance.

4 Conclusions

The introduction of advanced reporting capabilities has revolutionized the operational landscape of relevant mine services. Beyond providing fundamental production data, these reports furnish critical insights into coal yield, particularly in relation to longwall mining and total output. By meticulously detailing the weight of excavated material, including clean coal and rock, on a monthly and daily basis, the reports enable stakeholders to monitor feed composition to the Coal Processing Plant effectively.

The Gantt chart view offers a comprehensive visual representation of coal yield across corridor and production pits, facilitating nuanced analysis and decision-making. The integration of these reporting functionalities ensures that stakeholders receive real-time insights into operational status and resource utilization within the coal processing workflow. This empowers decision-makers to address bottlenecks and inefficiencies promptly, optimizing productivity and performance.

Moreover, the availability of accurate and timely reporting fosters better coordination and planning across mine services, fostering a more synchronized operation. Ultimately, these enhanced reporting capabilities drive operational excellence and maximize value derived from coal processing operations.

Thanks to this model, ongoing monitoring of feed composition allows for better operational and strategic planning. When significant overruns of the processing plant's capacity are identified, the mining schedule undergoes thorough analysis and redesign as needed. Thus, the implementation of advanced reporting capabilities not only enhances operational efficiency but also ensures adaptability and responsiveness to changing operational conditions, ultimately contributing to the overall success of coal processing operations.

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