Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Modeling of quality parameters of the coking coal as a process of adapting the output to the contracted parameters

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How to cite this article:
Dyczko, A. (2022). Modeling of quality parameters of the coking coal as a process of adapting the output to the contracted parameters. *Acta Montanistica Slovaca*, Volume 27 (1), 11-26

DOI:
https://doi.org/10.46544/AMS.v27i1.02

Abstract
Effective implementation of new market strategies faces the mining enterprises with new challenges, which require precise assessment instruments of the carried out business to be met at the level of mines, preparation plants, coking plants, and steelworks. These instruments include deposit, technological, and economic parameters, which together with a safety margin, determining a percentage reserve level of each parameter, shape the profitability of undertaken projects.
The paper presents the course and obtained implementation effects of a unique system for the production line management in the capital group of the Jastrzębska Spółka Węglowa (JSW) SA. The developed system allows optimizing the effectiveness of the production process in the system of one carried account within the entire mining group, which consists of mining plants together with preparation plants and coke plants. In particular, the paper raises the effectiveness issues of the system for deposit modeling and mining production scheduling in a multi-plant enterprise.
The heuristic technical architecture of the JSW S.A. production line management system, presented in the paper, allows to analyse the production process profitability in a carried account system in the area of mines, preparation plants, and coking plants of the mining group of the biggest European coal producer for metallurgical purposes.
The assumptions related to the construction of a system being in the future a basis for the realization of the Mine 4.0 idea are discussed.

Keywords
solving coal-coke corporation planning problems; geological modeling of the deposit; production scheduling; IT systems architecture; production quality management in mining

Introduction

The Jastrzębska Spółka Węglowa SA is the largest coking coal and coke producer in Poland and the entire European Union. The mining plants are located in southern Poland, in the Upper Silesian Coal Basin. The basic business of the company consists of the production and sales of hard coal (mainly coking coal), coke, and by-products. Maintaining coal and coke production at the quantitative and qualitative level required by customers is a crucial issue for the company.

The main issue consists of obtaining and maintaining the specified qualitative parameters of the coking coals required by the customer. Therefore, the issues of quality of coking coal can be considered both from the point of view of customers and producers. From a technological point of view, the quality parameters of coking coal determine the practical value of coal for the customers, i.e., its usability in the coking process, and for the producers - the technological regime appropriate to ensure the parameters of saleable coal required in the contracts. At the same time, the quality parameters decide about the production costs of finished products for customers, while for producers - about the obtained sale prices and incurred costs of concentrates production (Blaschke, 2009). Because of that, it is necessary to plan the mining in such a way as to be able to mine the coal with the required quality parameters, so that it does not lie in piles and wait for sale. The issue of coking coal quality is also perceived in other countries, where it is also a subject of scientific research. The Czech corporation OKD already in 2013 presented the effects of its studies on that (Danel et al., 2013). Analyzes have shown the need to integrate the measurement laboratory software into an integrated IT system that supports the sales of coal and coke. Scientists in Russia started studies on the coordination of coal coking coal mining by 8 mines (including an open-cast) to improve the quality parameters of the raw material (Berkutov, 2020). In the years 2018 and 2019 Russian mining plants improved and stabilized the quality parameters via the reorganization of raw material supplies.

In the past, the coking coal and coke market strongly affected JSW SA, and the company did not have any tools to prevent it. Therefore, actions were taken to build a modern production planning and scheduling system, driven by demand and quality (Demand and Quality Driven Management System).

Stabilization of production quality parameters as a basis for building a strategy of a mining enterprise

The production of hard coking coal and related customer requirements in terms of a high and stable product quality force the entrepreneur to forecast its specifications based on the in situ (in the deposit) tests of the raw material, prior to its mining and getting to the surface. Before 2015, JSW SA mining plants carried out forecasts independently, based on traditional methods of flat (2D) digital mining and geological maps, which were usually updated once a few months or even in longer time periods. The instability of the coal quality parameters was then treated as natural, related to the variability of the quality parameters of the coal deposits.

The IT system planned to implement was intended primarily to improve and make the company’s planning process in the field of mining more flexible by optimizing the quantity and quality of the coal mined, stabilizing the production quality parameters, and adapting the production to changing market conditions. An assumption was made that to accomplish this goal it is necessary to:

- develop a geological model to determine as accurately as possible the geological structure of the deposit and the quantity and quality of the mineral for each mine field,
- the process of planning and scheduling of development and mining works is based on the complete and verified geological data, including, in particular, a precise characteristic of the quality of the mineral.

Solutions in these two areas, which are only a fragment of the quality management system, were adapted to the specific requirements of JSW SA mines and preparation plants, for which high and stable quality coking coal is the main product. The parameters of seam coal, coal output, coal prepared in preparation plants, as well as coal in coke plants, storage yards and at various stages of logistic processes, are studied at individual stages of the quality management process (Burczyk and Marcisz, 2021).

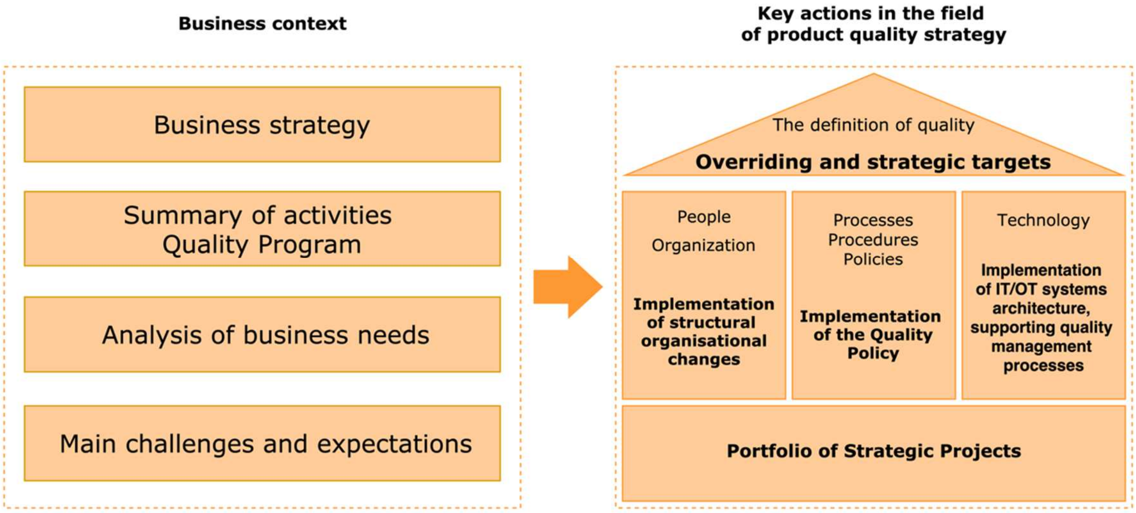

Fig. 1. Business context and crucial actions in the 'Product Quality Strategy' project at JSW SA

The yield and quality of the basic product, which is the blast furnace coke, decide about the economic effectiveness of the coking process. These values depend mainly on the quality of the coal raw material used in pyrolysis and, to a lesser extent on the coking technology. Therefore, the quality parameters, which characterize the usability of the coal for the coke production, decide on the practical value of the coking coal. The following should be mentioned among factors that decide about the practical value of coals (Ozga-Blaschke 2010):

— indices resulting from commercial and elemental analysis, which determine the volatile matter content and the share of ballast components and pollutants in coal, hence the total moisture, ash, total sulfur and phosphorus content; most of these indices are secondary features nature, shaped primarily by the coal preparation process;
— indices of coal microscopic assessment, i.e., the petrographic analysis and also the value and the distribution of vitrinite reflectivity;
— quality parameters characterizing the coke-forming properties of coal, such as caking power, dilatation, plasticity, and the expansion pressure, features developed primarily in the process of natural coalification;
— Coke Reactivity Index (CRI) and Coke Strength after Reaction (CSR) determined for the coke obtained from a specific coal.

Conditions of the IT system implementation process

Factors that activated the implementation of the discussed system process included the changing economic situation on the coal market and the need to increase the effectiveness of production. The undertaken actions resulted in the preparation of two key documents that shape this area in the JSW SA: the 'Product Quality Strategy' and the 'Management Policy for Deposit and Product Quality'. The second document determines, among other things, strategic projects in the field of quality management. The strategic projects were then defined in the technological domain and included in the documentation related to the technological solutions of the entire JSW SA. At the same time, they are a part of the general JSW SA IT strategy, which is presented in Fig. 2 in the form of key projects.

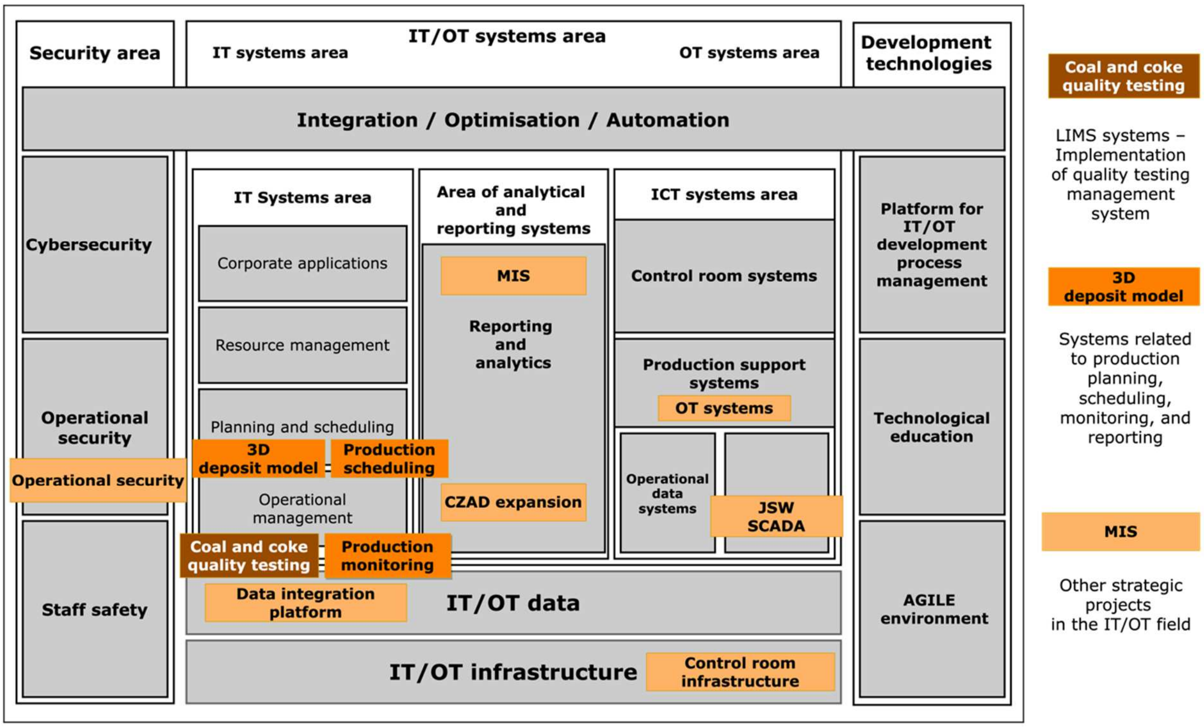

Fig. 2. Key projects in the field of quality management in the context of the general JSW SA IT/OT strategy (Burczyk and Marcisz 2021).

The preparation of those three documents resulted from the need to reduce the risk of business challenges faced by the company, and also from the need to maximize opportunities for further development of the company. To this end, two key areas were distinguished: operational management as well as planning and scheduling. The second key area comprised projects to develop a digital model of the deposit, and modern production scheduling, integrated on the company level, based on a 3D deposit model.

The implementation of the software is a complex process, analyzed many times within scientific research. A cascade model, defined by Royce (Royce, 1970), is the most common model of software implementation in big enterprises. This model was then modified and developed for applications in enterprises with operations on a large scale (Petersen et al., 2009). Practically all implementation cases in the Polish mining sector were based on the cascade model. It should be emphasized that many of them failed, or the implementation was completed, but with a missed deadline and increased costs. Already in the 1990s, software implementation analysis resulted in recognizing the problem in the form of ‘factors that distinguish successes and failures ...’ (Herbaleb, 1994). Over time, such factors became a tool for the assessment of the software implementation. So, during the software implementation, such factors may occur, which make its installation difficult. The results of scientific research on the implementation of IT solutions in the Polish mining sector (Krawczyk, 2019) have shown that there are many examples of the appearance of so-called implementation barriers. An implementation barrier is understood as the occurrence of such limitations and obstacles during the implementation, which result in a partial or total threat to the implementation (Krawczyk, 2019). In different areas of Polish mining, implementation barriers and decision-making issues occur (Palka and Stecuła, 2019; Stecuła, 2018; Stecuła and Brodny, 2018). Due to the actions aimed at reduction of barriers defined in the Polish mining sector, such as skills, communication, reserves, technological, organizational, interoperational, and usability barriers, were started prior to implementation (Krawczyk, 2019). Therefore, before implementation, a series of actions were taken to reduce the possibility of problems occurrence during this process.

The defined required functional scope of the system was achieved by performing an advanced process of components choice, in which the components were tested and evaluated by the JSW SA staff (Dyczko, 2021). This allowed to reduce the barrier of software usability.

The skill barrier was reduced using two methods. The first method consisted of choosing from employees those who know the individual areas best, most involved employees, and improving their skills by organizing a series of training courses delivered in the surveying-geological departments of all JSW mines. The second method consisted of cooperation under an agreement with the AGH University of Science and Technology, due to which seventeen new employees, young mining geologists were recruited. Under this cooperation, all members of a scientific circle, involved in geostatic and modelling of parameters describing the hard coal quality at the Department of Geology of Mineral Deposits and Mining Geology of the Krakow AGH, started the work at the JSW SA.

The technological barrier was reduced through a complex process of providing the staff with additional measuring equipment to acquire the data for deposit modelling, and with modern IT systems, which enable automation of measurement processes and data visualization. To this end, the implementation projects of 'Smart Weighers' and 'Neutron Analyzers' were started, which allowed continuous control of the quantity and quality of the mined coal transported by conveyors to coal preparation plants. Also, technological limitations were analyzed in terms of processing large amounts of data (Kosydor et al., 2020). Analysis has shown that the ICT infrastructure in the JSW SA required additional investments due to the large amounts of data collected during the operation of the system.

The organizational barrier was reduced by the establishment of a quality issues, with the task of analyzing the data and making strategic and current decisions in the field of mining operations, having broad competences to interfere in the field of stopping and restarting mining in any panel of any JSW SA mine. Because of this, a uniform and consistent model of mining operations planning and quality forecasting was introduced, which improved the development of short- and long-term production plans in terms of the quality stabilization of the final product (Barczyk and Marcisz, 2021).

The system was successively started in the years 2018-2020 and comprised establishing a geological database, filling it with data from 250 surface boreholes, 1,440 underground boreholes, more than 14,670 roadway profiling, 24,000 quality tests, 100 main faults, and 150 local faults. The final effect of the design work consisted of creating spatial, structural, and qualitative models of the deposit mined in JSW mines, as well as building strategic production schedules by 2030, together with a model of 700 km planned roadways and 480 mining longwalls, using 50 types of roadways supports and 25 algorithms of production limitations algorithms. Work related to the optimization and automation of operations in the system is now still being continued (Dyczko, 2021).

Digitization of geological data improved geological work in the field of geological data processing, both describing the deposit's structure and quality of the deposit. The changes in the quality of the deposit, their current trends and long-term forecasts are regularly analyzed by the mine teams to forecast the quality of the seam coal. Deposit and mining simulations, performed on their basis in terms of coal quality, provide now a significant source of managerial data (Peteresen i inn. 2009).

After completion of the pre-implementation work, the implementation of IT MineScape and Deswik solutions for deposit management and production scheduling in the JSW SA was started, which allowed to integrate and automate actions related to the production planning and quality management. The Integration Platform is the key element of the solution presented in the paper. Despite the fact that this is a central component of the solution, it does not provide any business functions. However, it is a significant instrument for information integration. Information integration allows a standardized exchange of data between systems developed in various technologies or using various communication protocols.

Parameterized interpolators used in the modelling of the coal deposits geometry and distribution of quality parameters in the JSW SA system

The data for the MineScape system originate not only from the examination of drill cores from surface boreholes but also from surveys carried out in the mine working. The geological service of the mines on a current basis performs sampling according to internal regulations and according to the guidelines of the Polish standard PN-G/04501:1998. Channel samples are taken from roadways and core samples from boreholes. The sampling grid is designed in such a way that the acquired qualitative information presents as accurate as possible the distribution of quality parameters in mining panels (Sosnowski, 2021).

Data originating from analyses are gathered in the GDB geological database (Table 1). The data loaded to the database are stored in the ArchiDeMes system and originate primarily from analyzes carried out by the Central Measurement and Testing Laboratory, Ltd. (Fig. 3). During the data loading to the GDB they are verified according to the rules defined by the users. The information collected on the coal quality is assigned to appropriate seam findings in geological wells or in the mine workings profiling.

Table 1. Quality parameters of coal collected in the geological database

Name of the value	Symbol	Unit
moisture content	W^a	[%]
ash content/air-dry state	A^a	[%]
volatile matter content/air-dry state	V^a	[%]
the Roga caking power	RI	-
free swelling index	SI	-
contraction	a	[%]
dilatation	b	[%]
total sulfur content	S_t^a	[%]

phosphorus content	P^a	[%]
chlorine content	Cl^a	[%]
calorific value	Q_i^a	[kJ/kg]
ash content/dry state	A^d	[%]
total sulfur content	S_t^d	[%]
volatile matter content	V^{daf}	[%]
coal grade		-
actual density	d_r^a	[g/cm^3]
apparent density	d_a^a	[g/cm^3]
coke reactivity index	CRI	[%]
coke strength after reaction	CSR	[%]
random vitrinite reflectivity	R_o	[%]
vitrinite content	V_t	[vol.%]
liptinite content	L	[vol.%]
inertinite content	I	[vol.%]
mineral content	M	[vol.%]

The coal quality originates because of interpolation of point findings for individual quality parameters obtained from the analyses of samples taken from wells or from sampling of mine workings. An assumption was made that key parameters, from the product quality point of view, obtained from samples in the as-prepared state (with ash content below 9%), will be modelled. At the stage of data preparation for modelling, for each individual point, quality the quality parameters were averaged within the full seam thickness or the face height (if comprised more than one seam).

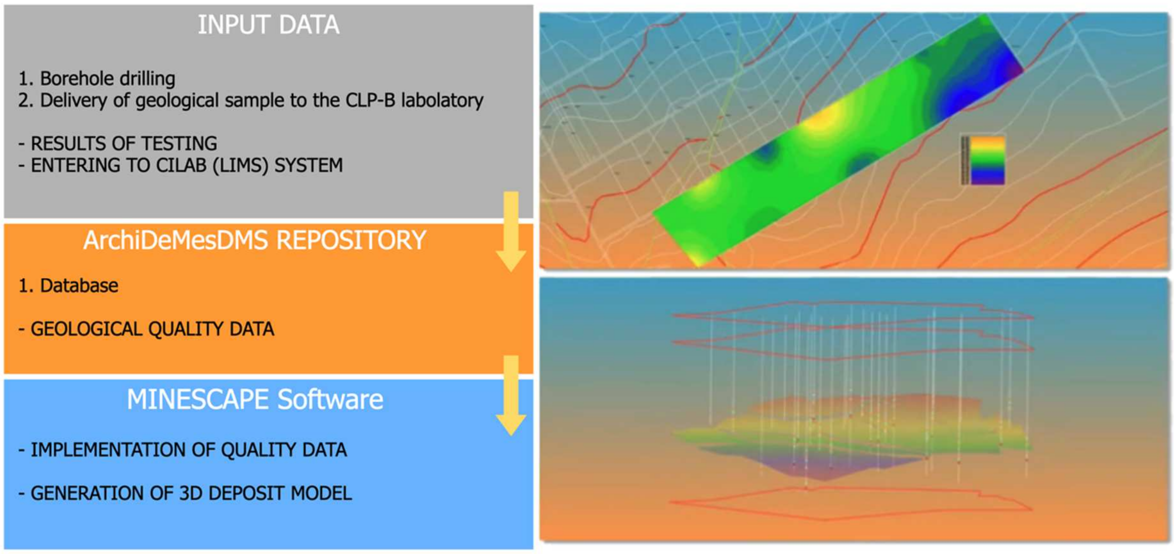

Fig. 3. The process of data processing in the deposit modelling system (Saganiak, 2021).

Interpolators - mathematical procedures, which based on point findings of quality calculate the forecast values of analyzed parameters at the nodes of a grid model, were chosen for individual quality parameters. Individual interpolators differ substantially in terms of requirements related to the input data, the scope of parameters allowing one to control the carried-out interpolation, and in the nature of resultant model surfaces (Fig. 4).

The selection of an appropriate interpolator of model quality parameters is also significant for the economic assessment of the planned mining (Kopacz et al., 2018, 2020a, 2020b). In the modelling of the quality of deposits mined by JSW SA mines, the IDW (Inverse Distance Weighting) and Height (using the trend and inverse distance surface) interpolators were primarily used. The applied tools also allow one to carry out a geostatic interpolation (ordinary linear kriging) of the studied quality parameters of coal.

The geostatic interpolation, referred to as kriging (Cressie, 1990), is used, if we assume that in the diversification of a deposit parameter there are random and nonrandom components, and that the structure of such a variable may be described with a function referred to a semi-variogram, which illustrates the dependence of an average diversification of a specific parameter on the average distance between the measurement points.

The kriging method may be used as an interpolation procedure only if the amount of data for the semivariogram is sufficiently large, which is possible only in more advanced stages of deposit exploration (Nieć, 2012). This procedure also requires carrying out the analysis of the variability for each of quality parameters in each modelled seam, which means that it is now used only in special cases (Fig. 5).

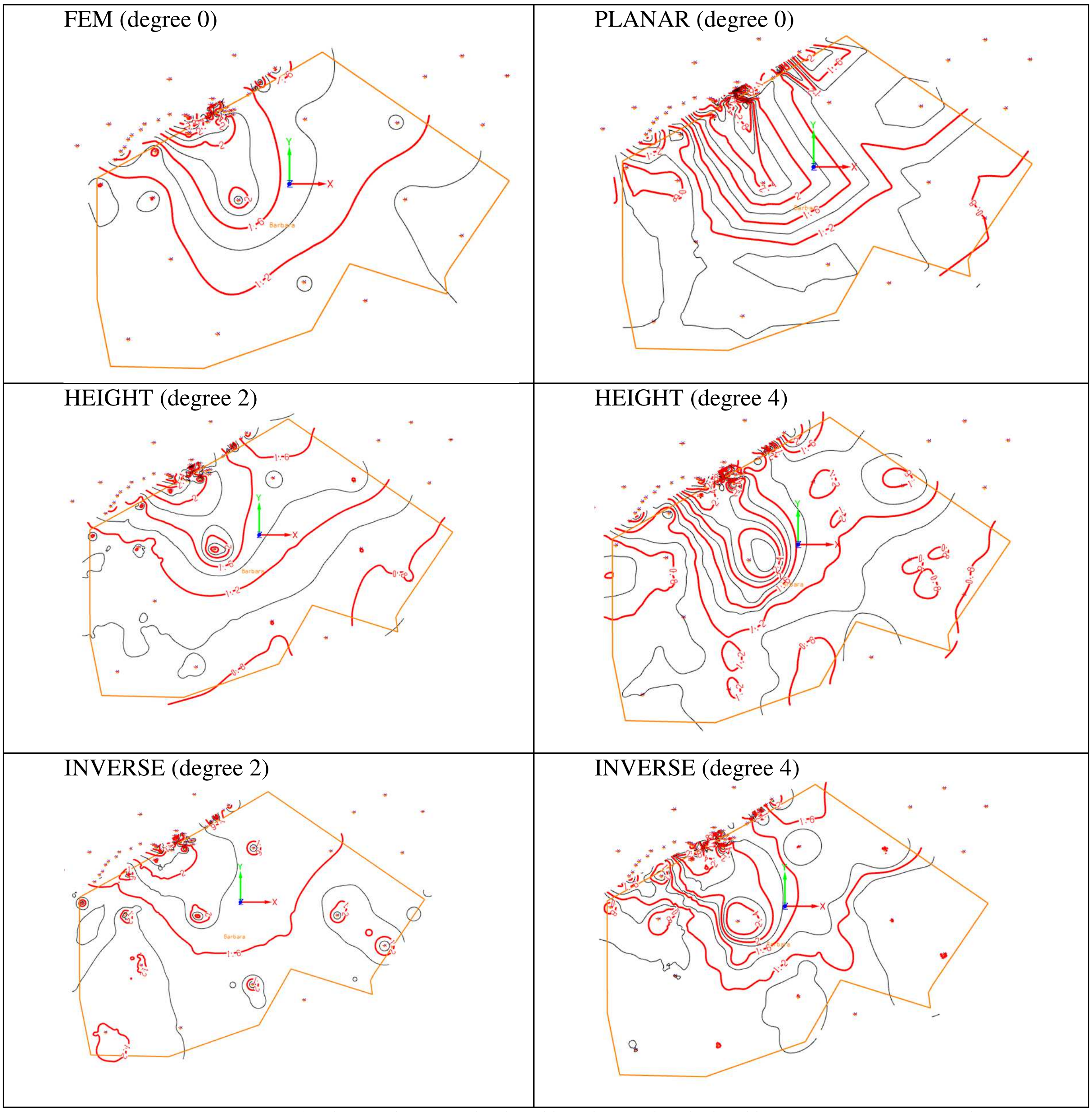

Fig. 4. Comparison of isoline quality maps developed based on grids calculated by means of various interpolators.

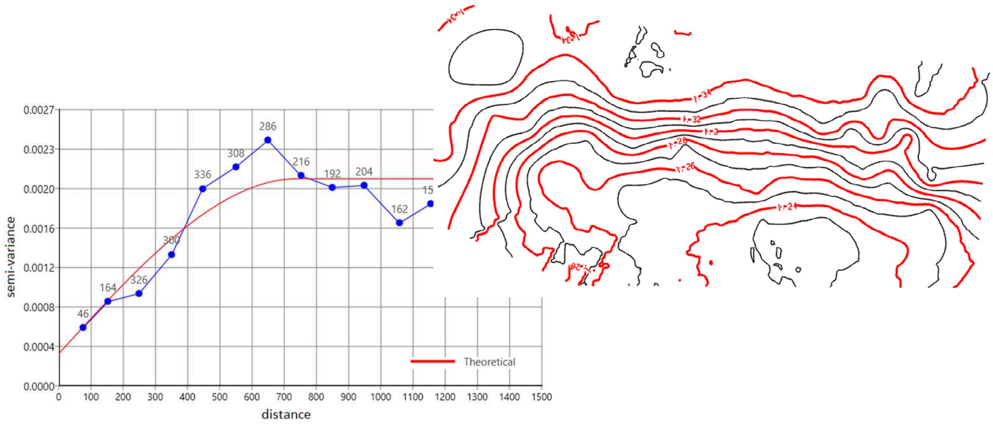

Fig. 5. Empirical and theoretical semi-variogram and an isoline map developed based on the kriging procedure for random vitrinite reflectivity in the selected seam.

The interpolation allows to fill the entire model space with the forecast values of quality parameters. They become elements of a 3D deposit model and may be visualized in the form of maps, cross-sections, or spatial projections (Fig. 6).

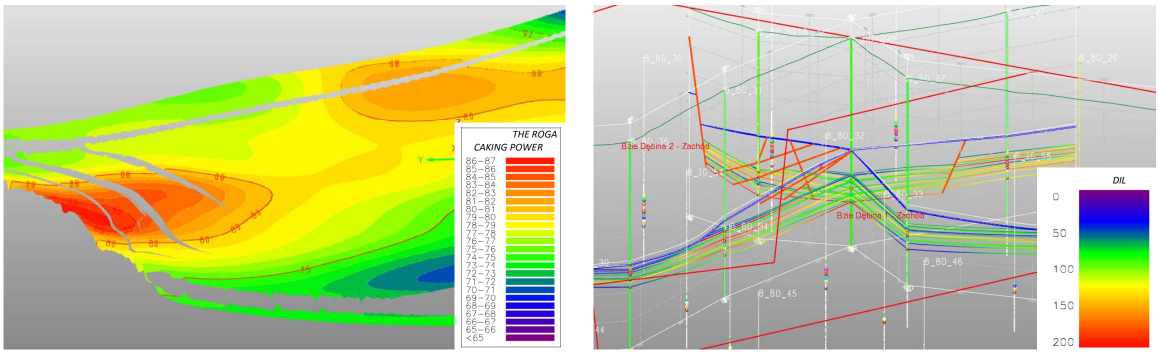

Fig. 6. The Roga caking power and dilatation on a spatial projection of the floor surface of the selected seam and on cross-sections through the deposit (Jamroży, 2019).

The technological classification of the coal grades used in Poland in the field of coking coals considers the volatile matter content V^{daf}, the dilatation b, the free swelling index SI, and the Roga caking power RI. The coal grade is not a numerical value, so it cannot be interpolated like the other quality parameters. In the implemented solution, depending on user needs, it can be interpreted and modelled in 2 ways:

1. As a class, interpolated between individual findings with the Polygon interpolator, determined for a given sampling point and seam.
2. As a value, calculated at each point of the model grid, resulting from the combination of the V^{daf}, b, SI, and RI parameters.

In the first approach, the coal grade at the point of analysis is used to chart the ‘influence zones’ of the given point. The coal grade is assigned to the given point based on the nearest finding. The second approach is based on expression surfaces, defined in the MineScape software, considering four quality parameters that define the coal grade at the point. Smooth transitions between individual coal grades in the model space are the effect (Fig. 7).

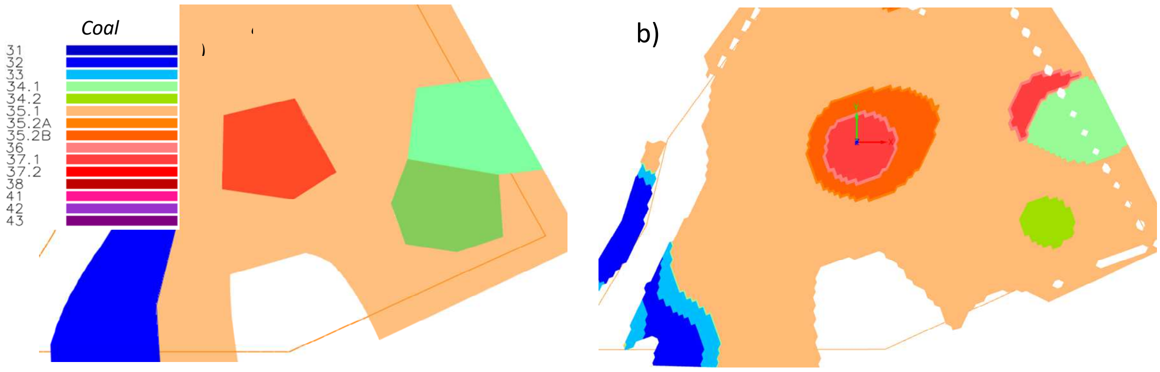

Fig. 7. Interpretations of the coal grade made by the Polygon interpolator (a), and by considering four quality parameters defining the coal grade at each point of the grid (b)

Determination of the quality of coal deposits planned to mine based on a digital model of the hard coal deposit

A mineral quality allows not only allows for the planning of the mining with respect to the expected quality parameters of the product, but also facilitates carrying out of actions related to the protection and recording of deposit resources. Resource reports produced acc. to Polish or international standards may consider selected quality parameters or their combinations (Fig. 8).

Seam	Coal grade 32.2	33	34.1	34.2	35.1	35.2A	35.2B	37.1	Total
362/1				2 393	7 898				10 290
362/2		1 370		1 572	14 417				17 358
363/1			311	5 587	10 565				16 463
401				343	22 032			489	22 864
402/1				773	12 835				13 608
403/1				403	26 868				27 271
403/2				1 208	22 282				23 490
404/1				81	29 316	893			30 290
404/2					6 083				6 083
404/3					19 150				19 150
404/4	401	1 088		122	16 706		1 047	271	19 635
405/1				70	43 858			980	44 908
Total	401	2 458	311	12 552	232 007	893	1 047	1 739	251 409

Fig. 8. An example of a report on a deposit model with a division of coal resources in the deposit into individual coal seams and grades

The solutions of the Deswik company, used in JSW SA, utilize a digital model of the deposit to plan the production of saleable coal with the required quality parameters. The geological information gathered in the GDB database and modelled in the MineScape software, e.g., in terms of the mineral quality, is updated in monthly intervals and transferred to the production preparation departments, which allows to update the production plans on a current basis. The basic challenge facing now JSW SA mines in the field of product quality now consists in ensuring that customers will receive coal, from which coke with stable parameters will be produced. Part of the mines also face requirements related to the reduction of coal produced for power purposes and simultaneous maximization of coal production for coking purposes (Matusiak and Kowol, 2020; Owczarek and Przontka, 2021; Kalinowski, Długosz and Kamiński, 2021).

A good and stable quality of the coal charge, from which coke is produced, is the condition to obtain a high quality of blast furnace coke. The charge for coke production is composed of a few coal grades with compatible coke-forming properties. The so-called base is a part of these coals, while others play the role of improving and leaning components. So, the quality shaping of the coal charge for coking starts already during mining in mines and preparing it in preparation plants, and it is continued next in coke plants (Ozga-Blaschke, 2010).

The practical value of coal directed to the coking process depends on very many quality parameters; coking coal preparation processes allow mainly to affect the moisture and ash content (Blaschke, 2009).

At the stage of designing the mine workings the system of development and mining workings is adapted primarily to limitations related to the deposit structure, in particular to tectonic disturbances (main faults, seams folding). At this stage, the structural model of the deposit is used primarily, the mineral quality model is a background and a potential indication with respect to the position and orientation of the mining longwalls (Fig. 9).

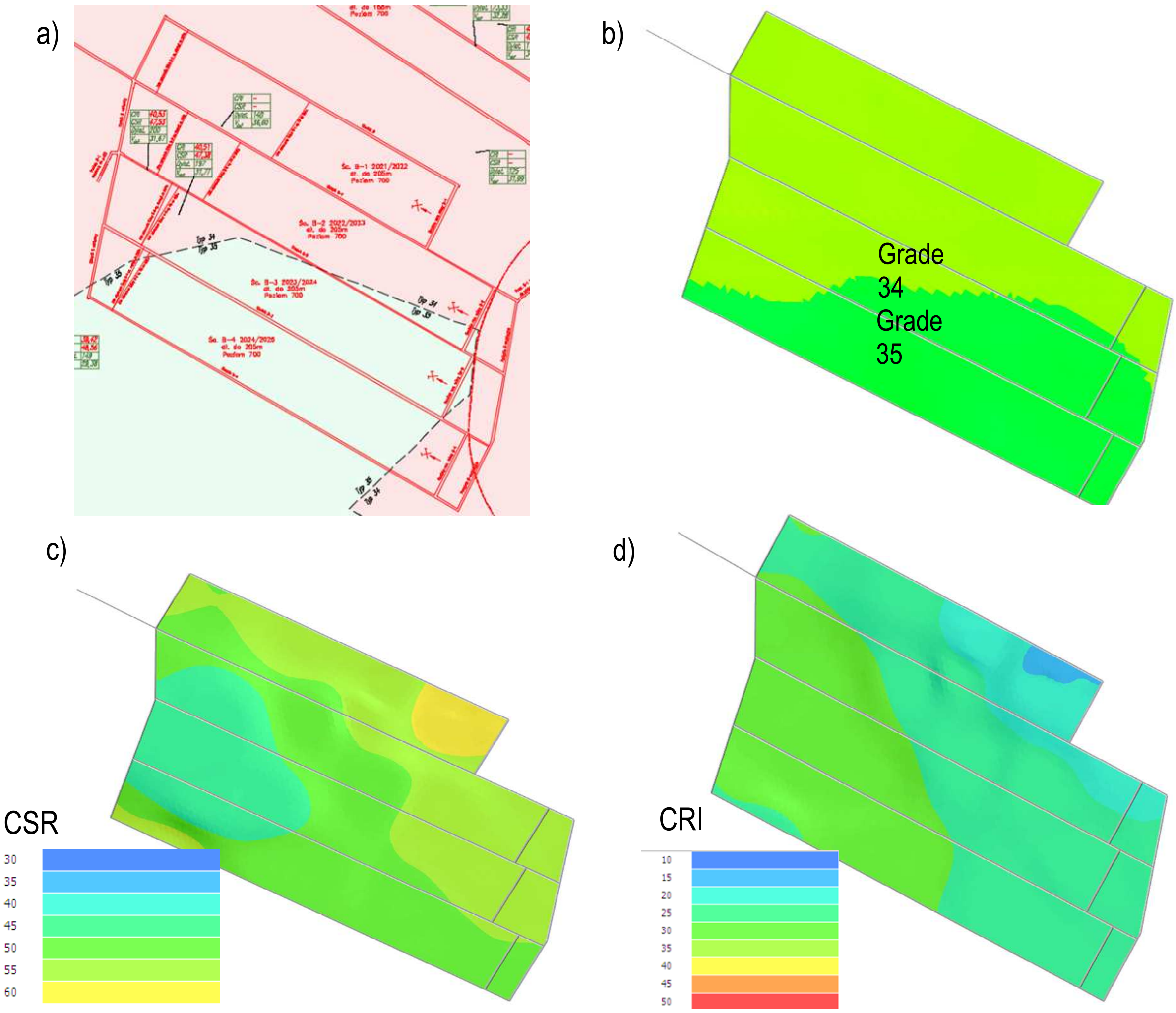

Fig. 9. Comparison of coal grades acc. to the seam map and the deposit model (a, b), and the distribution of the CSR (c) and CRI (d) values in the selected mining panel (Owczarek and Przontka, 2021).

The solids of the planned workings are uniformly divided into 25 m long. For each of such sections, the average values of quality parameters are read from the deposit model (Fig. 10). The solids of the workings divided in this way become tasks in the mining operations.

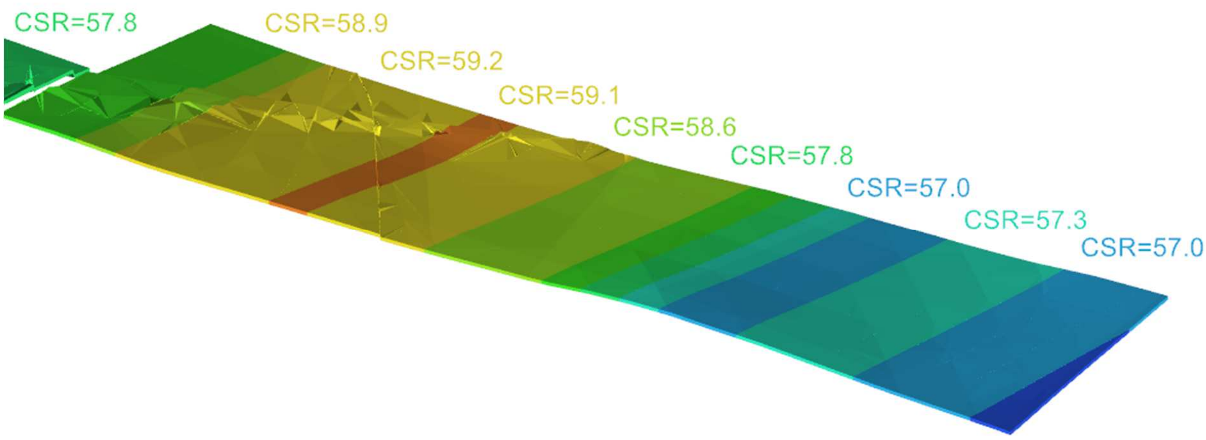

Fig. 10. CSR [%] values in the tasks of a selected mining longwall cut by two faults.

Application of the mineral quality model for long- and short-term planning to determine the quality of the output

At the stage of mining operations scheduling, the tasks are spread over time considering production targets and limitations related to the availability of production resources, and geological and mining conditions. Schedules are visualized primarily on the Gantt charts, which, depending on the needs, can display various production and quality data. In addition, the Deswik.Sched tool provides a possibility of permanent viewing the average parameters of individual longwalls, as well as the summary production data for the entire project in individual reporting periods of the schedule (Fig. 11).

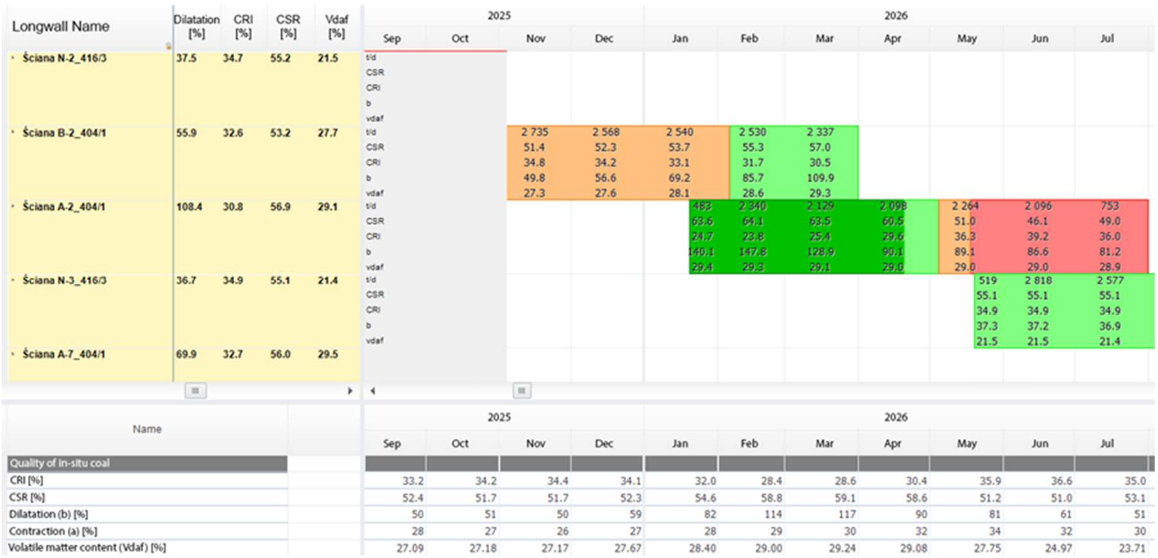

Fig. 11. An example of a Gantt chart with tasks coloring adapted to the CSR [%] value, average quality parameters for longwalls, and the resultant quality parameters of the coal production in individual periods.

The strongest possibilities for planning the quality of coal production exist in the stage of long-term (strategic) planning stage. Analysis of coal quality for individual longwalls allows iteratively the optimum sequence of mining and progress from the point of view of product quality stabilization on the optimal level optimal for the mine, and the expected output level observation conditions resulting from the used mining technology (Lewandowski and Kiełb, 2021).

The planning of mining with the use of detailed quality information from the deposit model allows to indicate groups of seams and longwalls, which excessive mining may be a threat to the product quality stabilization. Simultaneous mining of poorer quality longwalls with better quality longwalls allows to utilize the resources better without a negative influence on the product quality (Fig. 12).

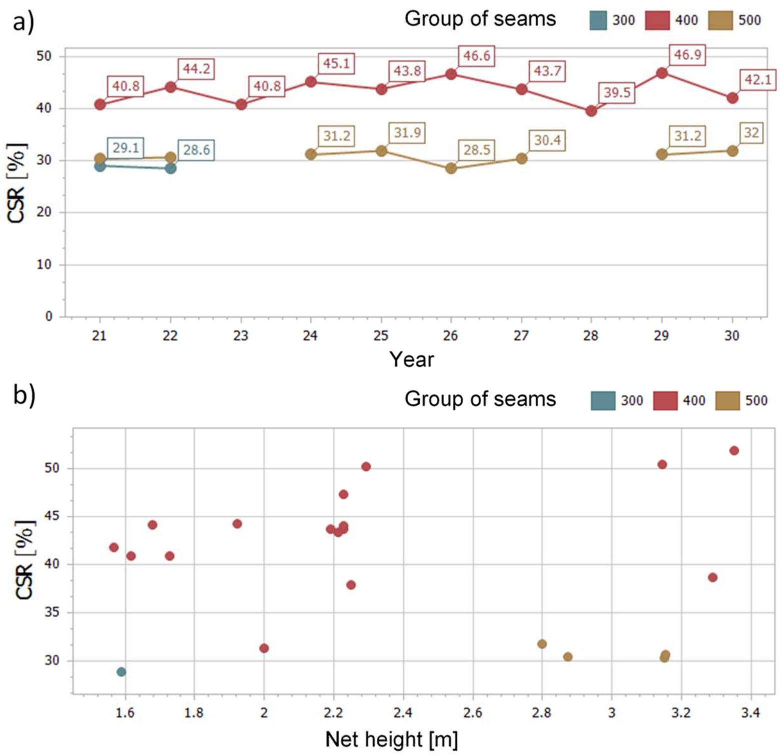

Fig. 12. Coal quality in groups of seams in individual years of mining (a) and in individual longwalls in relation to their net height (b).

In mining plants, which have technological solutions that enable selective mining and haulage of output, such solutions are used, which are aimed at forecasting the quality of individual output streams. In particular, the used solutions allow to direct the output stream by separating the output underground and directing it only to a selected technological line (Owczarek and Przontka, 2021). Together with underground and surface bunkers of raw coal, the solution used allows one to plan proper mixing of coal from individual technological lines and to obtain the expected quality parameters of coal sent to the preparation plant (Brejza, 2021).

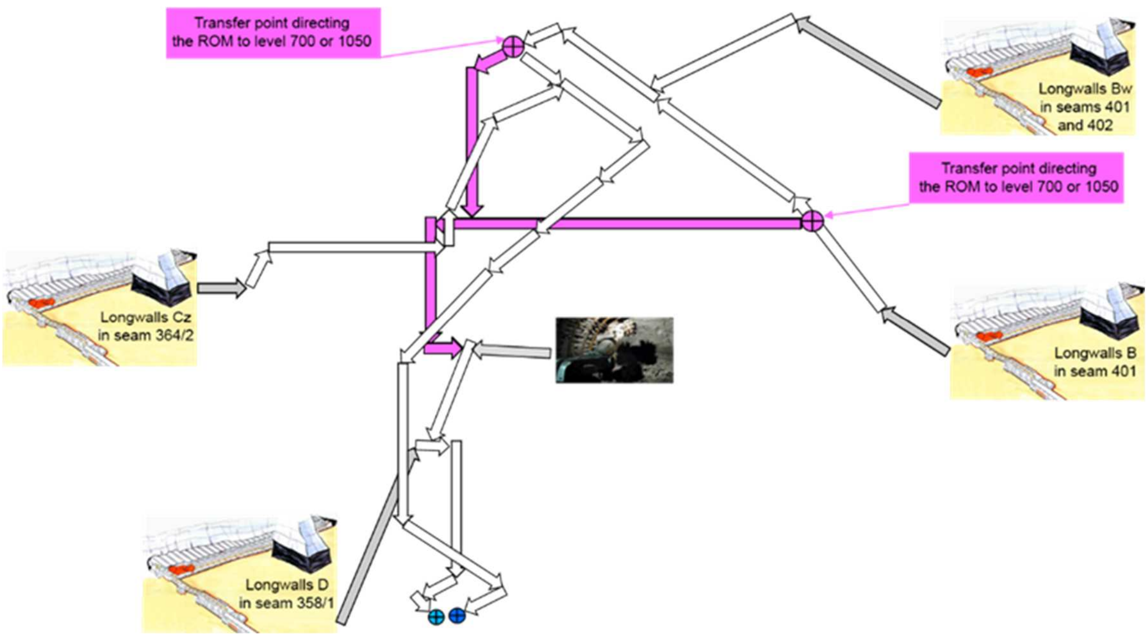

Fig. 13. Diagram of the main transport of KWK 'Budryk' with the possibility of directing the output stream, and graph of CSR and CRI changes on individual technological lines (Owczarek and Przontka, 2021).

The company has started actions aimed at increasing the production and sales of coking coal with stable and demanded quality parameters, e.g., through development of the resource base of the coking coal and related opening of new deposits and new mining levels. These actions, combined with progressing computerization of the entire production line, comprising among other things the modelling of deposits, forecasting, and monitoring and supervising the products quality on a current basis, allowed to stabilize substantially, and in certain cases also to improve the quality of coal output going to preparation plants (Fig. 14).

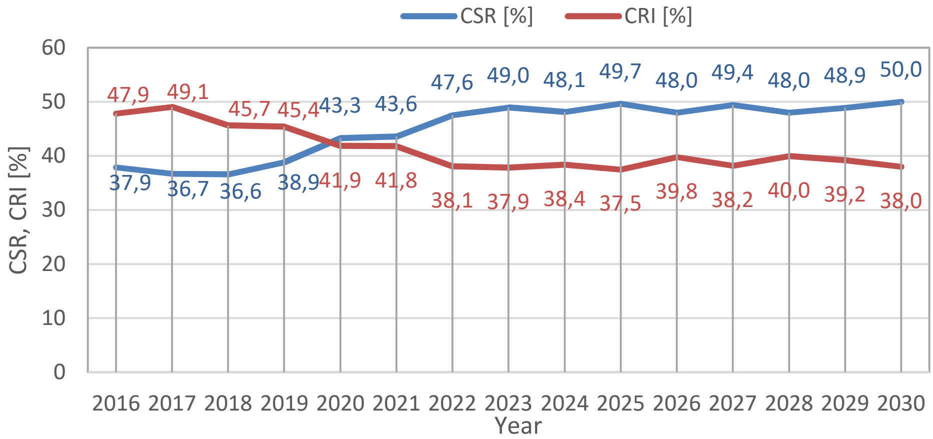

Fig. 14. Improvement and stabilisation of CRI and CSR [%] values of the deposit coal in the years 2016-2030 in a selected JSW SA mine. Years 2016-2021 - estimate based on longwall run schedules, years 2021-2030 - forecast made based on the deposit model.

In the short-term planning, when some longwalls are being mined, and for the next ones the development workings have already been driven, possibilities of quality control may be limited (Burczyk and Marcisz, 2021). However, in many cases, the permanent production monitoring allows for a quick reaction, consistent with the art of mining, also in such cases (Fig. 15), and to stabilize the quality on the expected level.

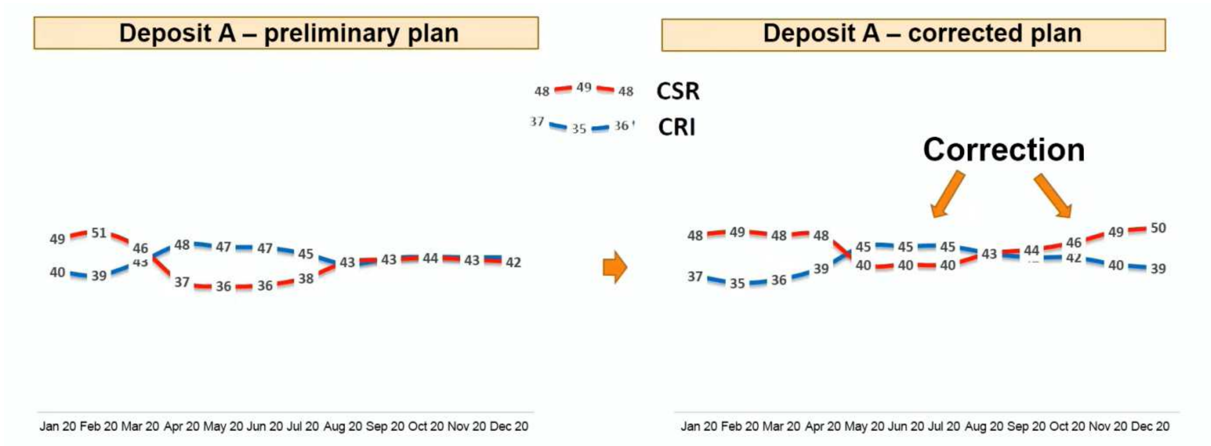

Fig. 15. An example of correction of a short-term mining schedule from the point of view of product quality (Burczyk and Marcisz, 2021).

Summary of implementation effects for the coal quality parameters of coal and mining planning a mining from the product quality point of view in the JSW SA

The following achievements and changes may be distinguished in the analysis of 2 years of the system operation:

— procedures related to the product quality management in the JSW SA have been prepared and implemented,
— geological databases of 6 mines have been built and ordered,
— IT tools for scheduling and deposit modelling have been implemented,
— geological models have been developed for strategic deposits, resource parts, and mining levels of all JSW SA mines,
— strategic production schedules have been developed, linked with deposit models,
— central strategic scheduling model has been developed, enabling the integration of mine schedules at the level of the JSW SA Management Board Office,
— foundations have been formed for the construction of the central database, which aggregates deposit models and production schedules on the level of the JSW SA Management Board Office, using the spatial data (Krawczyk, 2018).

Due to the implemented system, the employees can create mining variants, which are analyzed in any time interval due to the possibility of choosing any operation calendar. This may be, e.g., a monthly calendar broken down to days, an annual one broken down to months, but also a daily calendar, five-year, twenty-year, and even till the mine resources depletion calendar. Because of the permanent updating of the information in the database and a possibility of its rapid use and modifying, the designing process (both in the case of opening, development, and mining operations) is improved and accelerated many times as compared with the traditional methods, which enables:

- planning (short- and long-term) of the mining and technical designing,
- designing the opening, development, and mining operations,
- preparing a schedule of planned operations.

The developed digital model of deposit quality allows for automatic calculation of the quantity and quality of output and dirt in selected time slots, and after completion of the simulation - automatic generation of a forecast for all parameters related to the implemented mining project, such as the output quantity, dirt amount, quality parameters, etc.

The implementation and integration of quality testing processes, digital exploration of the deposit coal and its parameters, and, based on that information, automated planning and scheduling of the production and quality allowed to introduce a proactive production control, and obtain raised stable parameters of saleable coal. The implementation and integration of systems in the area of quality management now allows to:

- model the production and its key parameters management and forecasting, to obtain a stable level of production quality for coking coal customers and coke producers;
- plan and manage development operations and mining, to obtain and maintain the required levels of product physicochemical parameters;
- carry out selective mining through the control of the output quantity and quality, introducing output control with diversified parameters, and a selective preparation process;
- separate the product streams in terms of its quality, based on the determined key qualitative parameters and market demand, to maximize the sales prices - in 2020 price rises were obtained for coals delivered to strategic suppliers, due to maintaining a stable level of coking parameters of the produced coking coal;
- eliminate purchases of low-phosphorus coal from outside of the JSW CG.

After the implementation of the deposit modelling as well as production planning and scheduling, possible financial benefits, namely a return on the carried out so far, as well as operating actions carried out by the company Quality Office – estimated by the paper's author – based hypothetical negotiated changes of prices in the contract execution with a key customer, can reach even as much as a dozen or so million euros. The estimate was made based on the results of international market analyzes, carried out by globalCOAL (globalCOAL, 2021), which contained data on current and anticipated coal prices, market factors, and energy trends (Wróblewski, 2021; Wróblewski, Niekurzak, 2022).

Summary

The designing of mining and development workings in the 3D space, carried out based on the geological model of the deposit, describing both its structure and quality, has been carried out in the JSW S.A. for three years. Within the next 4 years it is planned to raise the level of data integration by the application of spatial databases storage (Krawczyk A, 2018). The developed mining variants are analysed in any time interval due to a possibility to choose any operations calendar. This may be e.g. a monthly calendar broken down to days, an annual one broken down to months, but also a daily calendar, five-year, or twenty-year calendar, till the mine resources depletion. Because of permanent updating of the information in the database and a possibility of its quick use and modification, the designing process (both in the case of opening, development, and mining operations) is improved and accelerated many times as compared with the traditional methods, enabling:

- planning (short- and long-term) of the mining and technical designing,
- designing the opening, development and mining operations,
- preparing a schedule of planned operations.

The developed model allows for automatic calculation of the quantity and quality of output and dirt in selected time slots, and after completion of the simulation - automatic generation of forecast for all parameters related to the implemented mining project, such as the output quantity, dirt amount, qualitative parameters etc.

The implementation effects, obtained due to computerization and automation of the deposit and product quality management processes, resulted in the stabilization of key contract parameters and enabled an increase in prices obtained in contact with key customers. The digitization and automation of qualitative data acquisition in the full production cycle enabled also monitoring and managing the complaint processes on a current basis, to minimize their financial effect.

The implemented system allowed full use of the technological capacities of the mines for the selective mining of the deposit. In these mines, coal during transport to the ground surface may be transported separately from each mining panel. Having precise data about the quality of the deposit, it is possible to control the quantity of coal mined from a specific longwall. The analysis of coal quality for individual longwalls allows iteratively showing the optimum sequence of mining and progress from the point of view of product quality stabilization on the level optimal for the mine and of expected output level.

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