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The geological modelling of deposits, production designing and scheduling in the JSW SA Mining Group

Introduction

The construction of a mining plant is classified as a project with a high degree of investment risk. This is not only because the time from the drilling of the first exploratory borehole to the start of operational activities of the investment lasts up to a dozen or so years but also because it requires the long-term ensuring of conditions for operational financing with the approval of a high risk of ultimate amounts of possessed geological and recoverable resources (measured and proved acc. to JORC classification), which during such a long period of time can drastically change (Wirth 2015). This is directly related to the necessity of looking for new solutions in the field of production management, which must be particularly flexible in the planning processes and respond appropriately quickly to market behavior. In recent years, planning processes became an interdisciplinary challenge, combining issues of geology, mining,

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and economy (Dyczko et al. 2014). The linking of these extensive issues causes numerous problems for enterprises in the mining sector. Therefore, modern methods of production management are based on a so-called systemic approach, which assumes that the enterprise is a whole, and efficient operation of this whole is affected by diverse technical, economic, sociological, and psychological factors. Thus, the enterprise is managed from the level of performance of the main objective of the enterprise, which is treated as a system which has a number of features determining its contact with the environment (Magda et al. 2010).

Modern methods of production management are, to a large extent, based on the computerization of the enterprise, which results in progressing the integration of the conducted processes. This phenomenon applies, inter alia, to production planning and designing, technical preparation, controlling the manufacturing processes, product quality and sales. Because of the application of computers, machinery and equipment controlled by them, a high degree of integration of system functions, broadly related to production, is achieved. This integration also comprises tasks related to production planning, designing, controlling the production flow, quality management, preparing offers for customers, studying effectiveness and calculating costs. These tasks are performed by means of special IT modules which use databases. Because of these, the processes of product design are supported by computer aided design systems (CAD), and the designing of technological processes is supported by CAPP systems. Additionally, the numerical control of machines, production planning and scheduling as well as the supervision of processing, assembly, and transport and warehouses systems are supported by CAM systems, and production quality processes are conducted by the CAQC system. The main reason for progressing computerization of the system, and thus the integration of processes that occur in it, is the need for the efficient and quick performance of production orders (Durlik 1996; Tarnowski 1997).

Methods from the MRP family (MRP I, MRP II, and MRP III) originated as a response to the low effectiveness of traditional methods for enterprise production management. They are based on scheduling production tasks on the basis of market demand forecasts for products of a given enterprise. The MRP I method (material requirement planning) was developed and popularized in the mid nineteen-sixties. It was created by the American Production and Inventory Control Society (APICS) and the method itself serves to manage the production and production inventories, and also methods to satisfy them that are related to the production tasks accepted for performance.

The MRP system features packages for computer scheduling, status monitoring, inconsistency detecting, as well as improving and updating, which ensures the efficient performance of these tasks. The MRP II method (manufacturing resource planning) is a natural continuation of MRP I method, developed in 1989 also by the APICS.

It originated as a result of the increasing needs to treat an enterprise as a holistic system consisting of strictly interrelated subsystems. This method expands the previous method by additional loops of feedback between performed production operations and other components, such as capital, machinery, spaces, information and work, due to which, the scheduling quality was improved.

The MRP III/ERP method (enterprise resource planning) is based on the MRP I and MRP II methods. The need for its development resulted from the imperfections of previous methods, such as the so-called ‘hidden costs’, caused excessive changes in schedules, excessive or unnecessary inventories, or the improper picking and packing of finished products, resulting in deficiencies and shortages and also in the reduction of revenues caused by overly long lead times of customer orders.

The ERP method provides the possibility of precise demand forecasting, combining such features of the MRP I method as the determination of demand for individual components and raw materials, and features of the MRP II method, such as capacity monitoring and planning. The forecasting of anticipated demand, which leads to the reduction of total inventories, is the most important part of MRP III. Methods from the MRP family originated to replace undereffective and imprecise methods for the control of inventories, while their further development expanded their functions to control other areas of enterprise. Under current market conditions, characterized by progressing digitization, integration, and fierce competition, MRP methods are good tools supporting enterprise in flexible production without deadlines missing, with permanent control of inventories and forecasting the volume of demand (Magda et al. 2010).

The development of IT, automation and robotics enables increasing the use of digital techniques for an increasing number of entities. This also applies to traditional sectors, such as the mining industry, for which the application of IT tools for data collection, storage, and processing should also be a priority.

Mining enterprises involved in the extraction of mineral raw materials have performed a series of studies in recent years in the field of deposit modelling and the mining production scheduling (Cowan et al. 2003; Chase et al. 2006; Kokesz 2006; Wasilewska 2007; Dyczko and Kłos 2008; Luppens et al. 2009; Janik et al. 2011; Sobczyk et al. 2011, 2016; Erdem and Güyagüler 2011; Dyczko et al. 2012, 2014a, b, 2016a, b, 2018, 2021a, b, 2022a, b; Jurek et al. 2013; Hausner ed. 2015; Coombes 2016; Wang et al. 2016; Sermet et al. 2016, Kowalczyk et al. 2016; Olesz 2017; Kijanka et al. 2017; Adeli et al. 2017; Galica et al. 2017; Kopacz 2017; Sermet et al. 2017; Naworyta 2017; Galica and Kulpa 2018; Wang et al. 2018; Wellman and Caumon 2018; Jelonek et al. 2017; Poniewiera and Sokoła-Szewioła 2019; Saganiak and Trybułowski 2019; Mól 2020; Kijanka 2020; Kopacz et al. 2020a; Kowalczyk 2020; Sosnowski et al. 2020a, b; Sumiński and Golda 2020; Cichowlas 2020; Owczarek and Przontka 2020; Urych et al. 2020; Kuchenbecker-Gacka et al. 2021, Gacka 2021b).

The methodology for the selection of IT tools for the development of a system of geological modelling of coal deposits as well as mining production design and scheduling in a multi-plant mining corporation presented in this paper was developed in the years 2018–2020.

Key commercial products of the company, in which an IT system for production management based on demand and quality of exported raw material was implemented, include coal and coke; the latter being a pillar of the European metallurgical industry. The strategic objective of the company consisted of improving the efficiency of deposit and product quality management, parallel to the proper identification of customer requirements and expectations in the field of qualitative and quantitative parameters of coking coal and coke. Thus, coal quality, at every stage of its production, is of key value for the company. To implement the strategy, the company commenced studies on the development and implementation of an IT system for deposit modelling and mining production scheduling, which should ultimately lead to the increased quality of the commercial product. The paper presents the initial stages of the system construction, which consisted of the selection of dedicated IT tools for the geological modelling of deposits and the designing and scheduling of production.

1. Deposit modelling and the production of a scheduling system in the JSW Capital Group – a foundation of 'QUALITY Programme'

Each case of mineral raw-materials mining performed using open cast or underground methods is classified as difficult mining operations. They are based on a chain of mining processes performed on the basis of project management rules. In a mining enterprise, managed in a modern way, the projects are based on rules determined by the Project Management Body of Knowledge, developed by experts in the field of project management. The growing competition on the market of mineral raw materials, determined by opening of the European market to competitors from outside the community, necessitates the need to look for new and reliable solutions for production management in a mining enterprise (Dyczko et al. 2014).

The Polish mining industry, being relatively modern in terms of machinery, also starts searching for new solutions cutting the operating costs of its business with increasing intensity, and at the same time improves the effectiveness of the performed mining. In global mining, the detailed preparation of a plan for opening geological resources and the selection of the optimal schedule of mining production, which would illustratively present the progress of mining over time and would enable the acquiring of potential investors, for many years has been the driving force to start and implement any mining project based on external financing.

The system for production management based on the demand and quality of mined raw material presented in the paper developed by the author is aimed primarily at improving and increasing the flexibility of the planning processes of the mining companies in the field of mining through the optimization of the quantity and quality of mined coal, stabilization of quality parameters of the output, and adaptation of the production to the changing market situation.

The new strategy of the JSW Capital Group defined goals for key areas of responsibility so that on the one hand, the aim was to reduce the risks and related business challenges, and on the other, to maximize opportunities resulting from social and economic changes.

The implementation of the 'QUALITY Programme' was made the key element of the JSW business strategy, comprising a number of actions enabling the ensuring of a uniform procedure for designing and planning production actions, deposit modelling and production schedules planning as well as monitoring and production quality supervision on a current basis, including:

- the building and ordering of geological databases of six mines;
- the implementation of IT tools for scheduling and deposit modelling;
- the development of geological models for strategic deposits, resource parts, and mining levels of all JSW SA mines;
- the development of strategic production schedules linked with deposit models;
- the development of a central strategic scheduling model enabling the integration of mine schedules at the level of the JSW SA Management Board Office;
- operations to build a central database, aggregating deposit models and production schedules planned at the level of the JSW SA Management Board Office.

A lot of effort was devoted to select and train appropriate employees in surveying and geological departments of all JSW mines. It is enough to say that in relation to system-development needs, the JSW signed appropriate agreements with AGH University of Science and Technology, employing seventeen young mining geologists, managing inter alia the entire scientific circle involved in geo-statics and modelling parameters describing the hard-coal quality at the Department of Geology of Mineral Deposits and Mining Geology of AGH, Kraków.

The development of teams was accompanied by an equally complex process of providing the staff with measuring equipment to acquire the data for deposit modelling, and modern IT systems enabling the automation of measurement processes and data visualization. To this end, 'Smart Weighers' and 'Neutron Analysers' implementation projects were started, enabling continuous control over the quantity and quality of the mined coal transported by conveyors to coal preparation plants.

Prior to carrying out studies on the development and implementation of the system for deposit modelling and production scheduling, the IT environment of the Group consisted of dispersed systems, inter alia, Geoslip and ArchiDeMeS, which were used for charting individual seams in the mined deposit and those that are planned to mine (that was nothing more than developing 2D models for individual coal seams). To this end, the CAD environment was used in the area of production planning (via overlays to the AutoCAD software). Spreadsheets were used in production scheduling, and after the completion of the entire process, the results were transcribed to the THPR module of the SZYK2 system. The SZYK system is a system for mine management support; its second generation (SZYK2) has been used in the Polish mining industry from the beginning of the twenty-first century (Stecuła et al. 2019). The THPR module was used, for example, for settlements and control of mining plans, schedules and the progression of development work; it allows the recording of elementary data on the performed and planned mining operations. In practice, the deposit management and scheduling of its mining was conducted with a low share of IT systems support. The majority of operations related to production management and scheduling was performed in a dispersed way using tools (.dwg, .xls files) without the possibility of automatic data exchange or even importing files. In addition, all these operations were performed on the level of individual mining plants (Ozon and Dyczko 2017; Dyczko 2021a, 2022a, b).

A decisive majority of operations were performed manually and in a decentralized manner.

The main limitation related to the lack of an integrated production planning and scheduling system was the requirement for a very long time to collect and standardize the data needed to build an effective mining strategy. The process of strategic plans development, using the dispersed tools, lasted from three to six months, which practically limited the possibility of updating it more often than once a year during the development of a technical and economic plan. This made it impossible to operate quickly and to update the mining strategy between the planning periods, e.g. in the case of the occurrence of macro-economic changes or other factors related to mining and geological conditions.

The second important limitation was directing the production planning and scheduling at the quantitative planning, at a small use of information on quality, which made it impossible to increasing the effectiveness of mining.

The dispersed IT systems used for planning, due to the adopted simplifications, in many places required providing data of various degrees of accuracy and granulation, which resulted in a very large amount of labor to reconcile the final data.

The fourth equally important limitation was the lack of the possibility to monitor on a current basis the deviation from plans in the field of qualitative deviations.

Because of this, it was important to conduct studies and take actions to comprise the entire process related to deposits modelling and production scheduling in centralized IT tools.

The system construction was started from ordering the area of quality management, Diagram 1, where the results of scientific research were taken into account (Grudowski 2004; Wojtowicz 2003, Kopacz et al. 2019; Dyczko 2021a, 2022a; Dyczko et al. 2020), which confirms that the implementation and operation of a quality-management system provides numerous benefits.

Internal benefits include the current monitoring of quality, the predictability of production quality, improvements in the effectiveness of operation, ordering actions in the organization, the involvement of employees in product or service quality shaping, economic benefits, supervision and improvement in processes within the organization, the allocation of rights and responsibilities to appropriate employees, motivation for improving and innovative actions, better and faster circulation of documents and information flow, improvement in communication inside the organization, less complaints and claims, and the higher motivation of employees. External benefits include an increased quality of manufactured goods and provided services, increased satisfaction of external customers, standardization of procedures related to customer handling, changed image – developing a quality-oriented organization, increased sensitivity to customer expectations, and easier access to the local and international market. The author assumed that to accomplish this goal, it is necessary to:

- develop a geological model for a determination of deposit's geological structure that is as accurate as possible, and the quantity and quality of the mineral for each mine field;
- base the process of planning and scheduling the development and mining works on complete and checked geological data, comprising precise characteristics of the mineral's quality in particular.

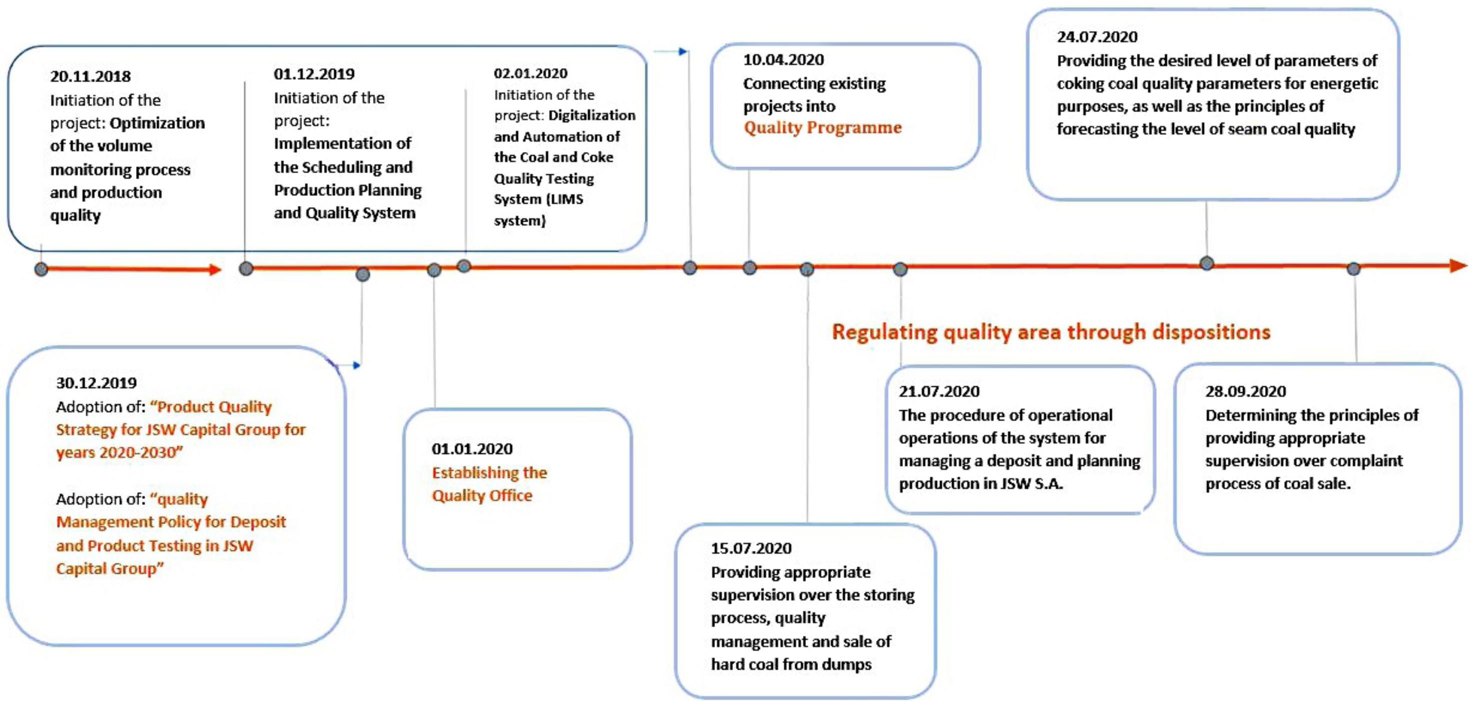

Diagram 1. Development diagram of proactive production control and stabilization of commercial coal in a coal–coke group (Dyczko 2022b)

Schemat 1. Schemat rozwoju proaktywnej kontroli produkcji i stabilizacji węgla handlowego w grupie węgiel-koks

Solutions in these two areas, which are only a fragment of the implemented quality management system, based on the demand and quality of the mined raw material, were adapted to specific requirements of the company mines and preparation plants, for which coking coal of a high and stable quality is the main product. Parameters of the 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 (Dyczko 2021a).

The author made the control of the entire process line, all its links in all the areas comprising the whole coal – coke process, the main function of the implemented quality management system based on the demand and quality of mined raw material.

The Mineral and Energy Economy Research Institute of the Polish Academy of Sciences (hereinafter referred to as MEERI PAS) fulfilled the role of technical adviser at the stage of tool selection and system construction, which was successively commissioned over two years and comprised the development of a database of geological data fed with data from 250 surface boreholes, 1,440 underground boreholes, more than 14,670 roadway profiles, 24,000 quality samples, 100 main faults, and 150 local faults. The final effect of the design work consisted in creating spatial, structural, and qualitative models of the deposit mined in mines, as well as the building of strategic production schedules by 2030, together with a model of 700 km planned roadways and 480 mining longwalls, using fifty types of roadway supports, and twenty-five algorithms of production limitations (Gacka 2021a; Dyczko 2022a).

The paper presents one of the first stages of system construction, specifically the selection of dedicated IT tools for the geological modelling of deposits and the designing and scheduling of production.

2. The concept of system construction in the field of a geological model of deposits and production designing and scheduling

The analysis of business processes and the choice of IT components necessary to develop both the geological model, which is the basic element of the entire project, and the production schedule, as an element of strictly mining domain, is always the basis for developing an IT system construction concept.

Progress in the computerization of the processes of mining production planning allows efficient modelling of the deposit structure and its qualitative parameters. In recent years, 3D modelling is a flywheel of the progress, which recently became an extremely important tool opening new development directions. Numerous pieces of software combine in the 3D environment to visualize the process of mining. Because of this, it is possible to obtain an almost real picture of mineral mining, practically with time synchronization (Kapageridis 2005). The use of IT tools to design and plan mining production substantially affects the quality of the performed mining and preparation process (Kaiser et al. 2002). Application within an increasingly wide scale of solutions, which herald gradual digitization in the mining industry (Stecuła and Palka 2019), results from the idea of Industry 4.0 and related progress in technology (Dyczko 2021a; Galica 2021; Palka and Stecuła 2018; Dyczko et al. 2013). However, the very application of IT tools does not guarantee success. For example, inaccuracy of the developed models can result in the origination of errors in the next steps of mining planning, which can in turn end with an unexpected increase in cost and a decrease in revenue obtained from mining activities (Wilkinson 2010). For this reason, the process of computerization is a major challenge for mining enterprises (Kosydor 2019) and any changes require effective management (Bąk 2018), and planning in particular. It is important that the process of the introduction of changes in this field is comprehensive in nature.

The geological model of the deposit is a digital computer representation of the structure of the mined mineral deposit, describing the deposit location, its spatial geometry, and the spatial diversification of mineral quality.

The aim of the geological modelling of the deposit consists in a determination of deposit geological structure that is as accurate as possible, and the identification of the quantity and quality of the mineral within the mine field. The deposit model is the basis for all actions related to the creation of mining plans and their optimization from the company economic calculus point of view. The geological model of the deposit originates primarily from geological observations performed both on the ground surface and also in mine workings. Thus, great attention was paid to actions aimed at the digitization of source materials and gathering them in a database of geological data.

The following assumptions were made for the business needs of the developed system for deposit data management:

- A numerical model of a deposit is from a quality point of view a new method to analyse the geological structure of the deposit, using the source information, existing now in an analogue form or as scans, including geological borehole logs and also 2D geological maps gathered in the system.
- The numerical model of deposit supports activities of the geological department related to designing and carrying out geological work as well as to interpreting and documenting the geological structure of deposit.
- The most important goal of the development of the deposit's numerical model consists in its importance from the point of view of the production objectives of a coal company: this is the basis for new solutions in the field of mining design as well as output and production planning.

The overriding objectives of the business concept within the area of production designing and scheduling was:

- improvement in the process of the designing of mining operations and scheduling, as well as production scheduling with the possibility of quick and dynamic updating, performing simulations, and creating many variants;

- the integration of a specific area with the other component processes of the production-management system of a coal-mining company;
- basing the process of geological planning on the geological model of the deposit, describing structural and qualitative features of the mined mineral.

3. Selected aspects of the application of IT tools in mining-production designing and scheduling

The planning and scheduling of mining production, primarily including the roadway operations (opening and development) as well as mining operations (longwall), is one of the basic engineering problems existing in every coal mine, both in Poland and worldwide.

At present, in the Polish mining sector, in most cases the processing of design data and also production schedules planning is performed in the Microsoft Excel environment. On the one hand, this tool allows quick access to table specifications of numerical data; however, on the other hand, an attempt to make a single production schedule requires spending more time than if it is conducted using software dedicated for such operations. The situation was entirely different with global leaders of coal production operating on the world market and for quite a long time understanding the necessity for using modern IT tools and their role in the mining production process. In the modern mining industry, any production plan starts with a digital model of the deposit, which is a foundation of the effective management of the resource base of every mine. From a practical assessment point of view, a properly developed model of the deposit allows the precise determination of the geological resources, taking into account qualitative and quantitative data. Because of conversion algorithms and geostatic methods, the qualitative data can differ from the actual situation; therefore, methods for improving the conversion algorithms of indicated values are continuously sought. The paper's author is convinced that with the development of the software itself, and also with growing computing capacities of computers, this role will continue to increase (Kaiser et al. 2002; Kapageridis 2005; Dyczko 2021b; Kicki et al. 2011).

The process of planning mining production is comprised of a number of decisions, which determine the possibilities to indicate the best production scenario, taking into account the observation of the highest level of safety and the production costs on an appropriately low level. The variability of economic parameters NPV (net present value) and DCF (discounted cash flow), and also uncertainties generated by the deposit model and technological processes force the creation of a few different production scenarios, in which a planner is capable of:

- developing a production plan comprising the possibility of the occurrence of failures in the technological line which originate from natural (e.g. water hazard, dynamic effects in the rock mass) and technological phenomena;
- optimizing the production plan in view of the effectiveness of the mining process and the quality of the obtained output;
- determining the life of mine.

In general, the process of planning mining production itself consists of a number of stages; however, in a simplified approach it is comprised of the determination of production targets, based on which, the plan of specific deposit/seam opening is implemented, and its mining is commenced.

In the universal conscience of miners' generations, the planning of mining production is comprised of the following three basic periods:

- long-term planning, the so-called 'long-term mine plan' (LTP), which usually covers a period of five to ten years; however, there are cases of developing 30-year plans, and it is comprised of the following actions:
  - the estimation of geological resources and commercial and recoverable reserves,
  - analysis of the market and available mining technologies,
  - determination of production targets,
  - indication of geological resources necessary to ensure production targets;
- medium-term planning, so-called 'medium-term mine plan' (MTP), which covers a period of three to five years, and the following actions are performed under it:
  - the updating and provision of more details of the plan up to one calendar year,
  - the determination of changes in the field of management of individual production stages,
  - the indication of changes in the field of the specific nature of mining methods for a given part of the deposit,
  - the determination of required human resources (HR plan),
  - the preparation of a financial plan and updating the budgeting plan;
- short-term planning (short-term mine plan, STP), which covers twelve to twenty-four months of mining production, and consists of:
  - the development of a precise production plan, together with the determination of costs, which cover the investment tasks.

From the point of view of a mining entrepreneur, the planning and settling of mining operations are the most important elements of deposit management. Decisions significant for the further operation of a mining plant, in particular in the field of the achieved economic results of the conducted business are made just at this stage of mining process.

4. Selection of dedicated IT tools for the geological modelling of deposits as well as production designing and scheduling

The assessment of production effectiveness performed on the basis of the mining schedule reveals the investment costs and profitability of the entire mining project.

The development of a production schedule, as an element of the process of mining planning, starts from drawing the development and mining workings into the geological model of the deposit in accordance with the adopted criteria for mining (e.g. the minimum thickness of the deposit). Depending on the software, this process can differ in terms of defining cross-sections of workings and creating contours of these workings; however, the determination of mining directions and symmetry axes of mining workings remains unchanged.

To obtain proper qualitative data of the mined hard coal, it is necessary to localize mining workings on appropriate depths, resulting from mining maps created in the surveying departments of mining plants. To this end, floor surfaces of seams are made based on the developed structural model of the deposit. Because of the complicated tectonic structure of mining areas, floor surfaces are frequently a system of a few planes of irregular shapes and sizes. It is necessary to remember that a spatial model of roadway and longwall workings is only a simplified variant.

Tools which enable the location of mining workings to be clearly determined in 3D space do not exist now (full information about the deposit is obtained after its extraction). Each schedule is developed based on the data directing the production processes. The following controlling parameters can be distinguished in this field:

- daily advances of roadway faces;
- daily advances of mining longwall faces (for hard-coal mines);
- rules of individual mining workings performance:
  - limit values of hoisting capacities of mine shafts,
  - limit values of preparation plants' capacities.

The next step of the process consists of defining a calendar of mining operations, in which holidays during the calculation period and the number of shifts per day as well as their effectiveness are shown. A parameter, referring to the number of repetitions per period is applied at the moment when the work on a specific day in the given working is performed e.g. every second Saturday. The schedule is based on a global calendar, which is assigned to each production resource. Contrary to roadways, for longwall faces (to facilitate the schedule performance) mining districts are formed. The results of each schedule can also be exported to the Microsoft Excel environment, where due to the application of a simple tool – a pivot table – it is possible to quickly tabulate the results of schedule depending on the needs of a specific mining plant.

The most important data are specified both in a numerical and graphical form, taking into account linear, bar, or other graphs defined by the planner. Tools for the results of work visualization are in most cases integrated directly with the scheduling software, allowing acceleration of the planning work and elimination of the necessity of purchasing additional IT tools to visualize the results. The setting up and averaging of data as well as their specification is performed in an intuitive and simple way for the designer. In the case of the majority of software, it is possible to notice a different trend related to the method of data specification. Some of the products feature tools which allow the creation of tabular specifications directly in the tool, others export the data to a .txt format, where in the latter case, the data is converted to the expected format. Results of the production schedule are also presented in the form of mining-operation visualization in workings, both in roadways and in mining faces. Each settlement period (day, month, year) is marked with a different color and is set up in the periodical settlement. During the project development, weight advances of mining are also used – the color of the working section changes after exceeding a multiple of the introduced weight of hard coal.

The basic objective of making a digital production schedule consists of preparing a full production schedule based on qualitative and quantitative parameters together with a number of graphs which later support production planning. Based on a Gantt chart, it is possible to check the performance correctness of the previously performed planning process and to present the entire schedule of mining production (short schedule) in a transparent way. The data originating from the deposit model are the basis to make calculations and are the foundation to create the results of the production schedule. Based on the data from the deposit model, the mining software performs a series of computations necessary to create a variant production schedule. Because of the substantial shortening of the computation time, as compared with methods based on Microsoft Excel, it is possible to create many production scenarios and to optimize them in terms of output maximization in a specific reporting period, gain an improvement in quality parameters, and introduce additional changes in production resources within a time horizon (a change of the shearer cutting the designed roadway working).

4.1. Presentation of available solutions

In the first stage of surveys, which were aimed at the selection of IT tools for the geological modelling of deposits and the designing and scheduling of the production of a multi-plant mining company, the available IT solutions for deposit modelling as well as the scheduling of mining operations were reviewed. The basic criteria for the selection of solutions of producers invited to participate in the presentations are comprised of:

- experience in the modelling of layered / stratified deposits;
- experience in implementations in underground mining of hard coal;
- experience in the modelling of geological disturbances;
- size of the company;
- references;
- the existence of a branch office in Europe.

During the analyses performed by the MEERI PAS from 2014, contacts were established with many companies delivering tools for deposit modelling and mining planning. These companies include: ABB, Dassault Systems, Deswik, Datamine, Geolisp, Leapfrog, Maptek, MineRP, RPMGlobal.

For the mining company presented in this paper, IT tools of six various potential vendors were indicated. Each company was asked for unit license prices of the suggested software for gathering geological data and modelling the layered deposits, as well as the designing and scheduling of mining by the longwall system, assuming the purchase of –ten to fifteen licenses. Requests were also made to estimate the costs of the software implementation for one selected deposit of the company or indication of additional information necessary for such pricing. They also received guidelines related to the suggested scope of presentation, which was split into two parts:

- a digital geological model of the deposit;
- mining designing and scheduling as well as planning and forecasting the production quality based on a digital geological model of the deposit.

The presentation is comprised of the following topics:

- functionality in the field of geological data gathering (geological database);
- functionality in the field of developing a geological spatial model of a bedded deposit;
- functionality in the field of designing and scheduling.

The majority of the presented solutions were offered by single companies, which ensured that the entire functional range is covered by their products. In one case, the solution was suggested by cooperating companies. Representatives of one of the companies did not attend the meeting and therefore their solutions were not considered. The analysis was finally performed for four potential IT solutions.

4.2. Evaluation of the presented solutions

The presented solutions were evaluated by employees of the company and of selected subsidiaries. In particular, they represented:

- mining plants:
  - surveying-geological department,
  - production preparation department;
- management board office;
- entity providing IT services for the company;
- entity providing R&D services for the company.

During each presentation, the employees were given questionnaires for the presented solutions evaluation. The questionnaires were prepared separately for the geological part and for the production planning part. Each questionnaire was comprised of twenty-one questions. In each questionnaire, seventeen questions related to the evaluation of the suggested solution on a scale from one to five in the field to which the question was related. Altogether, approx. 180 questionnaires were given to presentation attendees. Arithmetical means were calculated from all questions scored as the final assessment of the solution in the given questionnaire during the working out of the questionnaire results.

Four IT solutions for deposit modelling as well as production designing and scheduling were presented during the organized meetings. During all presentations, attendees completed a total of 121 questionnaires and entered 1,771 partial evaluations. Figure 1 presents the number of collected questionnaires by the organizational units.

The largest number of questionnaires were completed by employees of the Surveying-Geological department, next by those from the Production Preparation department.

Respondents also declared previous knowledge of the presented solutions (Figure 2). Only Solution 4 was previously well known to the majority of respondents.

Figure 3 presents average scores of individual solutions.

Solution 2 received the highest scores, both in the field of geological modelling as well as for the designing and scheduling of mining operations (Figure 4). This solution also received very similar scores and as the only received the highest score in the area of designing and scheduling. In this field, the other solutions received much lower scores. Solution 4 also received a high result. Solutions 1 and 3 were scored much lower.

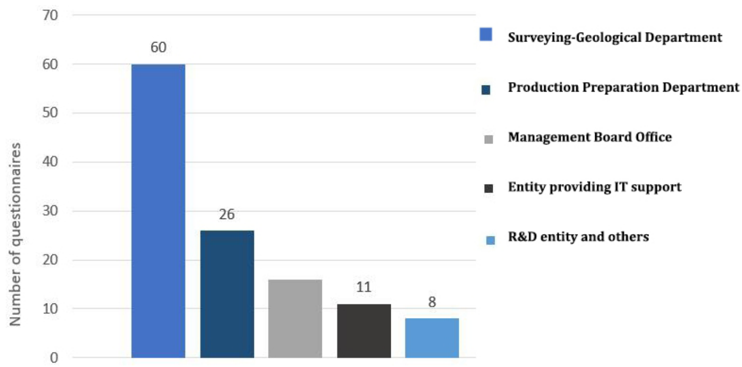

Fig. 1. The number of collected questionnaires by organizational units (own study)

Rys. 1. Liczba zebranych ankiet według jednostek organizacyjnych (opracowanie własne)

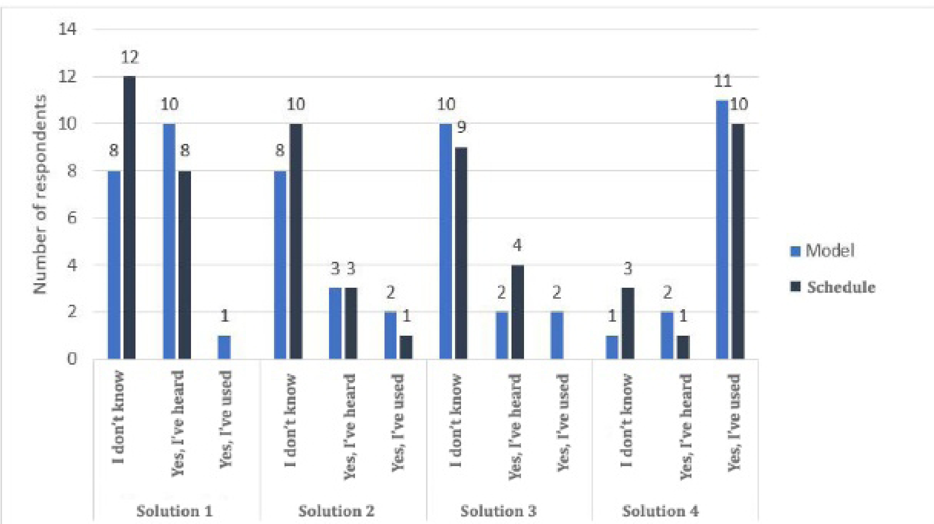

Fig. 2. The number of collected questionnaires by organizational units (own study).

Rys. 2. Liczba zebranych ankiet według jednostek organizacyjnych (opracowanie własne)

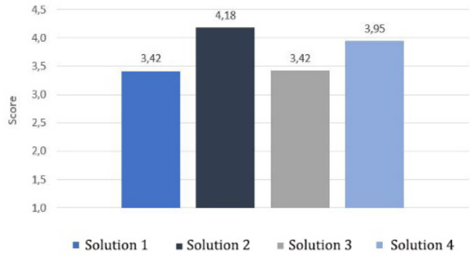

Fig. 3. Average scores from questionnaires (own study)

Rys. 3. Średnie wyniki z kwestionariuszy (opracowanie własne)

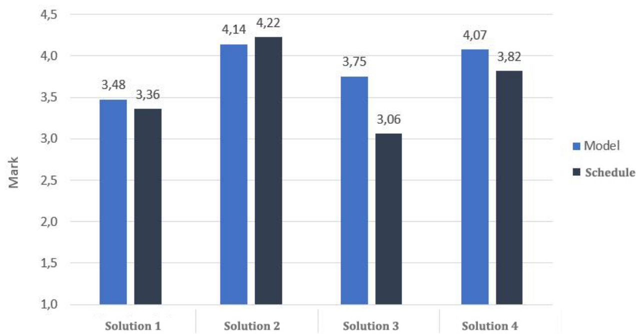

Fig. 4. Average questionnaire scores for geological modelling and the designing and scheduling of mining operations (own study)

Rys. 4. Średnie wyniki kwestionariuszy modelowania geologicznego oraz projektowania i harmonogramowania robót górniczych (opracowanie własne)

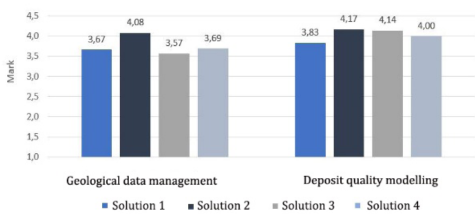

Fig. 5. Average scores from questionnaires – detailed results – subject-matter requirements – deposit model Part 1 (own study)

Rys. 5. Średnie oceny z ankiet – wyniki szczegółowe – wymagania merytoryczne – model depozytu Część 1 (opracowanie własne)

Detailed results of questionnaires in relation to subject-matter requirements in the field of the deposit model (Figures 5, 6, and 7) and scheduling (8, 9, and 10) are presented in the figures below.

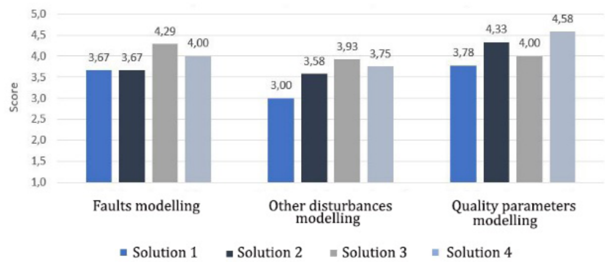

Fig. 6. Average marks from questionnaires – detailed results – subject-matter requirements – deposit model Part 2 (own study)

Rys. 6. Średnie oceny z ankiet – wyniki szczegółowe – wymagania merytoryczne – model kaucji Część 2 (opracowanie własne)

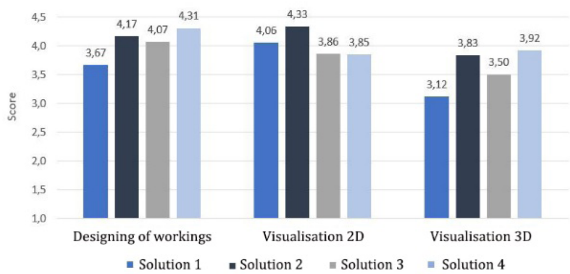

Fig. 7. Average marks from questionnaires – detailed results – subject-matter requirements – deposit model Part 3 (own study)

Rys. 7. Średnie oceny z ankiet – wyniki szczegółowe – wymagania merytoryczne – model depozytu Część 3 (opracowanie własne)

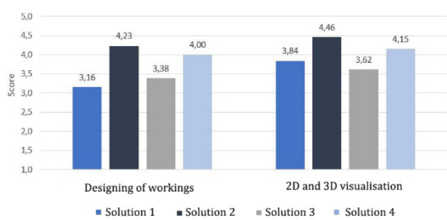

Fig. 8. Average scores from questionnaires – detailed results – subject-matter requirements – scheduling Part 1 (own study)

Rys. 8. Średnie oceny z kwestionariuszy – wyniki szczegółowe – wymagania merytoryczne – harmonogram Część 1 (opracowanie własne)

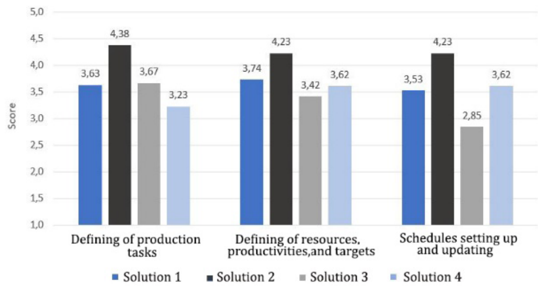

Fig. 9. Average marks from questionnaires – detailed results – subject-matter requirements – scheduling Part 2 (own study)

Rys. 9. Średnie oceny z kwestionariuszy – wyniki szczegółowe – wymagania merytoryczne – harmonogram Część 2 (opracowanie własne)

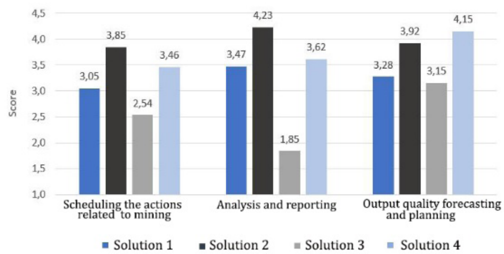

Fig. 10. Average marks from questionnaires – detailed results – subject-matter requirements – scheduling Part 3 (own study)

Rys. 10. Średnie oceny z ankiet – wyniki szczegółowe – wymagania merytoryczne – harmonogram Część 3 (opracowanie własne)

4.3. Selection criteria for the recommended solution

The presented results of questionnaires filled in by the employees of the company and its subsidiaries were only one of the criteria for the optimum solution selection. Altogether, four main criteria for the evaluation of presented solutions were considered:

- technical criteria – average scores from questionnaires;
- technical criteria – expert assessment of the technical adviser (MEERI PAS);
- business criteria – developed together with the Management Board Office and the technical adviser;
- IT criteria – developed by a subsidiary, providing IT support for the company.

The presented solutions were evaluated on a scale from one to five in accordance with each of the aforementioned criteria. The overall score of the solution was the arithmetic mean from individual criteria.

Based on the conducted presentations and general knowledge of the presented solutions resulting from previous analyses and implementations, the next technical evaluation was performed based on MEERI PAS experts' opinions. The evaluation was conducted based on the same questionnaires. Solution 2 was evaluated as the best (Figure 10). According to this evaluation, Solution 1 obtained a result only slightly lower than Solution 2, and at was much higher than in the questionnaire evaluation by the company employees.

In the field of deposit modelling, Solution 1 was evaluated as the best. In the field of designing and scheduling, Solution 2 was evaluated as the best. Clearly, lower scores of Solution 2 primarily resulted from the lack of an IT solution to run a geological database and a relatively low degree of satisfying requirements related to the production scheduling. The low scores of Solution 4 resulted from a low degree of satisfying the requirements related to the production scheduling. Figures 11 and 12 present results of evaluation performed by the technical adviser.

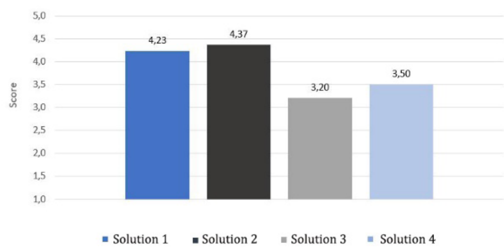

Fig. 11. Technical criterion – MEERI PAS expert's opinion (own study)

Rys. 11. Kryterium techniczne – opinia eksperta IGSMiE PAN (opracowanie własne)

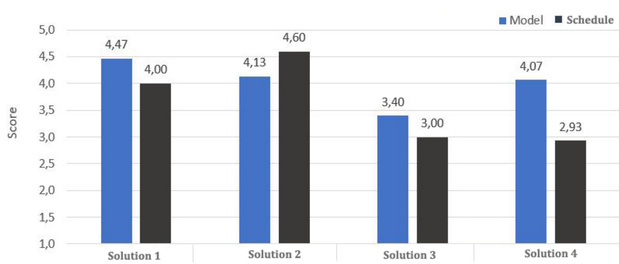

Fig. 12. Technical criterion – MEERI PAS expert's opinion in individual areas (own study)

Rys. 12. Kryterium techniczne – ekspertyza IGSMiE PAN w poszczególnych obszarach (opracowanie własne)

The business criterion, developed by the Management Board Office of the company in cooperation with the technical adviser, comprised a number of sub-criteria used to evaluate the presented solutions:

- experience of the company in the Polish mining sector, with a special emphasis on hard-coal mining;
- experience of the company in the global mining sector, with a special emphasis on hard-coal mining;
- size of the company and certainty of the company operations continuity as a supplier;
- possibilities in the field of customer support;
- existence of branch offices in Poland/Europe.

Each solution was evaluated according to those sub-criteria on a scale from one to five, and the arithmetic mean of scores was taken as the final value. According to business criteria, Solution 2 was evaluated as the best. Also Solution 3 received a good result. Figure 13 presents the final results of business evaluation.

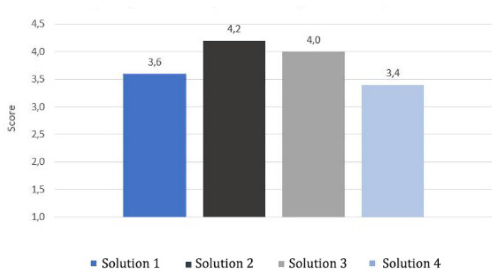

Fig. 13. Final results of business evaluation (own study)

Rys. 13. Końcowe wyniki oceny biznesu (opracowanie własne)

The IT criterion was prepared by the subsidiary, which provides IT support for the company, and had a form of a questionnaire delivered to companies participating in presentations. The questionnaire contained 111 questions related to the reference architecture of the solution, applied server and database technologies, security mechanisms, and related to the evaluation of the user interface and of the method of application distribution. After the analysis of answers, ninety-seven key questions were selected, which were used to compare the solutions.

Individual items in the questionnaire were evaluated as 0, 0.5, or 1 point. One point was given when the supplier provided an answer and the presented solution was consistent with the standard in the company. A score of 0.5 point was given when the supplier provided an answer, but it was incomplete or the presented solution was not consistent with the standard but could be allowed for use in the company. Points were not given if there was no answer or if the solution was inconsistent with the standard. So the maximum score was ninety-seven points. All of the offered products met at least the minimum requirements for entry to the IT environment of the company. Systems which obtained the highest score allowed a more flexible planning of the target architecture of the implemented system, or had additional security mechanisms. Because Solution 2 consisted of products from two different companies, the results of both questionnaires were averaged. Results, originally determined in percent, were converted into a scale from one to five.

Solution 2 was also evaluated as best in the IT evaluation. Figure 14 presents the results of the IT evaluation.

Individual groups of criteria – technical (questionnaires), technical (experts), business, and IT – were used to calculate the final evaluation of the presented solutions as an arithmetic mean of the four main criteria. Figure 15 presents the final evaluation of the presented IT solutions. Based on this, Solution 2 was indicated as meeting the technical (both according to the questionnaire and technical adviser's opinion), business, and IT requirements to the largest extent.

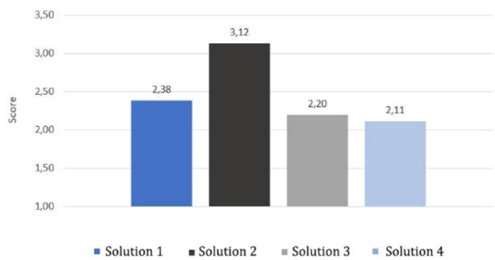

Fig. 14. Final results of the IT evaluation (own study)

Rys. 14. Ostateczne wyniki ewaluacji IT (opracowanie własne)

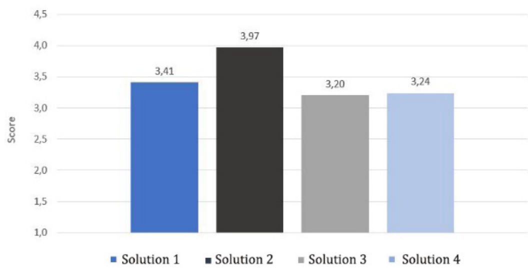

Fig. 15. Final evaluation of the presented IT solutions (own study)

Rys. 15. Ocena końcowa prezentowanych rozwiązań informatycznych (opracowanie własne)

Conclusions

The digital transformation, in particular in the mining industry, is frequently perceived as a badly implemented and not always fresh automation of back office-related processes and actions, sometimes with the use of expensive hardware. However, an objective reality of the global mining sector operates at high variability, complexity, and uncertainty with regard to the method and scope of operations in the nearest years.

An effective method for addressing all related risks and increasing business competitiveness consists of a well-thought holistic digitization, which starts from the preparation of strategy and ends with operational activities in which the actual possibilities offered by modern technology are used.

Enterprises from the oil and gas sector became convinced of the fact that an increase in effectiveness in the mining sector due to the introduction of digital solutions was already possible a long time ago. They have been using 3D modelling from the 1990s, which enabled a reduction of the costs of reservoirs prospecting by an average 40%, and a reduction in expenditures related to reservoirs maintaining of 10%.

Digitization is a trend which cannot be reversed, to which it is necessary to prepare, and which should be properly managed. Key success factors in the use of new technologies include an accurate analysis of needs, a detailed review of solutions present on the market and the proper defining of requirements.

A technological dialogue conducted by questionnaire surveys, supported with experts' opinions, was applied to select the software for designing a system of deposit modelling and for the designing and scheduling of mining operations. Questionnaires originated on the basis of presentations, covering the functionality in the field of geological data gathering, developing a geological spatial model of a bedded deposit, as well as designing and scheduling. The presented solutions were next evaluated, via questionnaires, by the employees of the company. In addition, four groups of criteria were prepared – technical (questionnaires), technical (experts), business, and IT – on the basis of which, the final evaluation was performed. Ultimately, Solution 2 was selected as that which satisfied the technical, business and IT requirements of the planned system to the highest degree.

The indicated IT solution was implemented and became one of the basic tools for modelling hard-coal deposits and also for designing and scheduling of the mining operations in the company.

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THE GEOLOGICAL MODELLING OF DEPOSITS, PRODUCTION DESIGNING AND SCHEDULING IN THE JSW SA MINING GROUP

Keywords

production planning, mining, production quality management,
geological modelling of deposit, coal-coke group

Abstract

The paper presents the analysis of IT tools selection to develop a system of deposits geological modelling as well as production designing and scheduling in a hard coal mine. The presented concept creates a subject-matter foundation of the solution supporting the decision making system in the field of production activities performance, with the use of IT solutions and monitoring of end product quality, implemented under the paradigm of so-called Intelligent Mine.

A technological dialogue carried out by questionnaire surveys, supported with experts' opinions, was applied to select the software for designing a system of deposit modelling, and for designing and scheduling of mining operations. Questionnaires originated based on presentations, covering the functionality in the field of geological data gathering, developing a geological spatial model of a bedded deposit, as well as designing and scheduling. The presented solutions were next evaluated, via questionnaires, by the employees of the company. In addition, 4 groups of criteria were prepared: technical (questionnaires), technical (experts), business, and IT, based on which the final evaluation was carried out. Ultimately, Solution 2 was selected as that, which to the highest degree satisfied technical, business, and IT requirements of the planned system.

The indicated IT solution was implemented and became one of basic tools for modelling hard coal deposits, an also for designing and scheduling of the mining operations in the company.

MODELOWANIE GEOLOGICZNE ZŁÓŻ, PRODUKCJA PROJEKTOWANIE I HARMONOGRAMOWANIE W GRUPIE GÓRNICZEJ JSW SA

Słowa kluczowe

górnictwo, węgiel koksowy, planowanie produkcji górniczej,
modelowanie geologiczne, planowanie jakości produkcji górniczej

Streszczenie

Rozwój informatyki, automatyki i robotyki umożliwia coraz większej liczbie podmiotów zwiększenie wykorzystania technik cyfrowych lub komputerowych. Dotyczy to również branży tradycyjnych, takich jak górnictwo, dla których stosowanie narzędzi informatycznych do gromadzenia, przechowywania i przetwarzania danych również powinno być jednym z priorytetów. Grupa Kapitałowa JSW SA, zajmująca się wydobyciem węgla kamiennego oraz produkcją koksu, przeprowadziła badania w zakresie opracowania i wdrożenia systemu do modelowania złoża oraz harmonogramowania produkcji górniczej. Celem stosowania wdrożonego systemu była realizacja nadrzędnego celu Programu Jakość Grupy Kapitałowej, czyli zwiększenia efektywności zarządzania jakością złoża i produktu handlowego. W artykule przedstawiono jeden z etapów badań, którym był wybór dedykowanych narzędzi informatycznych dla potrzeb modelowania geologicznego złóż oraz projektowania i harmonogramowania produkcji.

Opracowane rozwiązanie pozwala na stałą aktualizację informacji w bazie danych, szybkie ich wykorzystanie i modyfikację oraz usprawnienie procesu projektowego (roboty udostępniające, przygotowawcze, jak i eksploatacyjne). System pozwala na planowanie (krótko- i długoterminowe) eksploatacji oraz projektowanie techniczne, projektowanie robót udostępniających, przygotowawczych i eksploatacyjnych oraz wykonanie harmonogramu projektowanych robót. Umożliwia automatyczne obliczanie ilości i jakości urobku oraz skały płonnej w wybranych przedziałach czasowych oraz przygotowanie prognozy dla wszystkich parametrów dotyczących wykonanego projektu wydobycia, takich jak: ilość urobku, ilość skały płonnej, parametry jakościowe itp.