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Construction of a heuristic architecture of a production line management system in the JSW SA Mining Group in the context of output stabilization, quality improvement and the maximization of economic effects

Introduction

The market of mineral raw materials, and in particular of hard coal, has recently become very unpredictable. The situation with the raw materials market is becoming problematic for businessmen who must very flexibly adapt their companies to variable market conditions in order to maintain viability of their mining projects. In the JSW Capital Group (JSW), which is involved in mining hard coal and producing coking coal, profit is generated at the entire Group level, where mines are a significant initial link of the production process, with determined production costs. Two paths of mining cost development exist:

- pragmatic, consisting of the rationalization of costs at their point of origin (saving actions);
- mining the deposit according to quality (controlling the allocation of mining).

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The effective implementation of the aforementioned actions requires precise assessment instruments at the mines, areas, districts, and production-face level. 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. Intensive mining of the coal deposit, carried out for more than a half century by JSW mines, resulted in the depletion of resources, and means the necessity to reach for more and more difficult in mining and poorer quality parts of deposit situated at the boundaries of the current mine fields. As the further existence of all JSW mines depends on carrying out mining in just such areas, the asking of the following question becomes increasingly justified: *Is the mining of poorer quality and technically more difficult to mine deposit parts economically profitable?*, *What is the way to skillfully control mining to acquire the raw material as long as possible in an optimal way, from both economic and technical points of view?*

The Integrated Production Quality Management System, created and now being developed in the JSW Capital Group, is to help answer the above questions; it was created mainly to enable managerial staff of various levels to control the process of deposit mining in order to improve the economic effects of the performed mining operations.

The paper presents the issues of designing the architecture of an IT system for deposit modelling as well as the mining production scheduling in the JSW SA. The developed system allows control over the entire technological line of the JSW Capital Group, thus in all areas covering the whole coal/coke process. The system was 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 profiles, 24,000 quality tests, 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 JSW mines, building strategic production schedules by 2030 together with a model of 700 km planned roadways and 480 mining longwalls, and using 50 types of roadway supports and 25 algorithms of production limitations. The work related to the optimization and automation of operations in the system is still being continued.

Quality is the key term in the production of coking coal. According to the PN-EN ISO 9000:2015-10 standard (Standard PN-EN ISO 9000:2015-10) the quality is the degree at which a set of inherent properties satisfies the set requirements. In other words, it is a set of properties and numerical characteristics of a product or service, which affect their capability to satisfy the needs (Mikulski 2008). Raising the issue of product quality, it is necessary to refer to the quality of the entire coal production process because in accordance with the JSW strategy, it's overriding goal consists of increasing the effectiveness of the deposit and product quality management, at simultaneous proper identification or customer requirements and expectations in relation to parameters of coking coal and coke quantity and quality. A great weight should be given to quality not only in basic processes (winning operations and coal preparation) of coal production but also in the other partial processes (Turek 2010), i.e. development, auxiliary, and accompanying processes. It should be emphasized that the first crucial surveys and actions in the field of quality must take place at the stage of deposit exploration. Because of that, JSW carried out studies on developing and implementing systemic support for deposit modelling and production scheduling.

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

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

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

- geological databases of six 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;
- operations to build a central database, aggregating deposit models and production schedules, are planned at the level of the JSW SA Management Board Office.

A lot of effort has been devoted to selecting and training appropriate employees in surveying and geological departments of all JSW mines. It is enough to say that in relation to the system development needs, the JSW signed appropriate agreements with the AGH University of Science and Technology, employing 17 young mining geologists, managing *inter alia* the entire scientific circle, involved in geostatics 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 with modern IT systems to enable the automation of measurement processes and data visualization. To this end *Smart Weighers* and *Neutron Analyzers* 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 and deposit and other deposits that were planned to be mined in the future (that was nothing more than developing 2D models for individual coal seams). In the area of production planning, the CAD environment was used (via overlays to the AutoCAD software). Spreadsheets were used in production scheduling, and after 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; it's second generation, SZYK2, has been used in the Polish mining industry from the beginning of the 21st century (Łukaszczyk and Koszowski 2018; Łukaszczyk 2019). The THPR module has been used, for example, for settlements and control of mining plans, schedules and the progress of development work; it enables the recording of elementary data on performed and planned mining operations (Puzik 2012). In practice, deposit management and scheduling of its mining was carried out with a low share of IT systems support. The majority of operations related to production management and scheduling were performed in a dispersed way in tools (.dwg, .xls files), without the possibility of automatic data exchange or even file imports. In addition, all these operations were carried out on the level of individual mining plants. A decisive majority of operations were performed manually and in a decentralized way.

The main limitation related to the lack of integrated production planning and scheduling system was the very long time required 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 3 to 6 months, which practically removed 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 consisted of directing the production planning and scheduling the quantitative planning, at a small use of information on quality, which made the increasing of mining effectiveness impossible.

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

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

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

2. Technical architecture of the production line management system of the JSW SA group in the light of global experience of the mining sector computerization development

2.1. Analysis of IT tools

IT tools used to design and plan mining production appeared on the market more or less at the same time, substantially affecting the quality of the performed mining-preparation process (Kaiser et al. 2002). The first packages of software supporting the mining of raw materials appeared as early as in the 1970s, and the pressure of gold producers to search for effective tools minimizing losses related to exploring, documenting, and mining overly diluted raw material is considered the main catalyst of their development – let us remember that average gold prices on the global stock exchanges at that time did not exceed USD 50/oz. The tools created at that time were developed both by mining corporations themselves and by research centers, whose staff were overnight becoming the creators of innovative products, which on a competitive market were quickly changing into commercial software, which was frequently more functional than that developed within mining companies (Kapageridis 2005). Finally, at the beginning of the 1980s, the majority of world corporations abandoned their own research projects aimed at building IT tools supporting the process of mining production planning and scheduling in favor of solutions offered by specialized companies.

In recent decades, we have witnessed the incessant development of mining production planning and scheduling systems (Stecuła et al. 2017; Stecuła and Brodny 2017) and one can easily risk a statement that now it is not possible to find a company involved in minerals mining which would not use engineering software in some form. Particular progress in the field of deposit modelling and the use of IT tools in the process of mining is visible in the deep mines of noble metal ores, in which numerous companies obtained the first direct benefit from those tools used by reusing information which was previously considered to be useless. 3D modelling is a flywheel of the progress that we witness nowadays which recently became an extremely important tool, opening new development directions. In deep mines of noble metals in South Africa, practical planning and management of the mining production is carried out by means of geophysical techniques (Campbell 1994; De Wet et al. 1994; Pretorius et al. 1987, 1994, 2003).

2.2. Analysis of computerization solutions for production lines

The issue of developing a platform enabling the modelling and control of mining and geological objects has been raised in previous research (Lukichev and Nagovitsyn 2018). Researchers in the Russian mining institute, Kola Science Centre, RAS, have developed the MGIS MINEFRAME – a mining geology IT system. The system allows modelling of the mineral deposit by means of 3D digital models, including the description of the geometry and properties of objects, and to create a block structure. The authors emphasize that the application of modern laser scanning and picture processing techniques enables the quick design of digital models of objects. The system guarantees gathering and making available the data on objects as well as their accessible visualization. It supports forecasting the variability of deposit parameters based on the developed algorithms. The system is used to collect and process the monitored data on the rock mass condition, the location of machinery and equipment, the distribution of staff, and the operation of mining machinery and equipment. As the authors state, the system is to support the resolution of many mining problems based on:

- the structure of mining object models, together with a possibility to store information on the objects location, geometry, and properties;
- displaying the object in a vector and block form;
- the automation of access to data and methods;
- the integrated database with access by many users, sampling, and loading object models to a graphic editor;
- a set of systemic tools allowing automation of the resolution of mining problems based on unified models of mining objects.

The system is created to assist in the designing of open-pit and underground mining operations, the optimizing of mining and operational operations planning, mining machinery management – at ensured geo-mechanical mining safety.

2.3. Assumptions about the production line architecture development in the JSW SA

The JSW SA has carried out the implementation process of a geological modelling system – MineScape, and a system for production planning and scheduling – Deswik. In the ultimate shape, MineScape was designed to partly replace the deposit modelling and to provide approved structural and qualitative parameter models of the deposit in individual collieries of the group directly to the Deswik platform. In turn, the Deswik system was designed to download data from the MineScape system, process them, and export them in a form used by the SZYK system. The implementation of the production modelling and scheduling system allowed movement from analogue to digital maps in the geological division of all mines. The systems allow for the precise forecasting and controlling of the production quality.

The first of the systems – the deposit modelling system – enables developing a digital spatial geological model of the deposit with a possibility to use the selected database to manage the geological data and make them available to other IT tools. The geological deposit model developed in the system is understood as a digital computer geological model of the mineral's deposit, describing the deposit location, its geometry, and the spatial diversification of the mineral quality. The aim of the geological modelling of the deposit consists in the as accurate as possible determination of the geological structure of the deposit, and 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 with regard to the group economic calculation. The object of geological modelling may be comprised of, within a selected range, the physical properties of the deposit overburden rock as well as that of rocks surrounding the coal seams. The model may be also enhanced with information supplementing a full picture of the deposit's geological situation, such as the results of hydrogeological observations. The geological model of the deposit is primarily based on geological observations, carried out both on the ground surface and also in mine workings. Because of this, great emphasis was placed on actions aimed at the digitization of source materials and gathering them in the geological database. It is worth emphasizing, that a geological interpretation of the gathered data performed by an experienced geologist is also an indispensable element of the geological modelling process. The following assumptions were made for the needs of system development and implementation:

- a numerical model of the deposit from a quality point of view is a new method to analyze 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 seam maps gathered in the system, and functioning under the control of the GEOSLIP and ArchiDeMeS software;
- the target numerical model of the deposit supports activities of the geological department related to the design and conducting of geological work, as well as to interpret and document the geological structure of deposit;
- the most important goal of the numerical model of deposit maintenance consists in its importance with regard to group production objectives – it should be the basis for new solutions in the field of mining planning as well as output and production planning.

The second system for production planning and scheduling (Deswik) enables, for example, the creation of integrated schedules of longwalls and opening-development operations, reporting, and the development of qualitative and quantitative forecasts. The system also enables the graphical visualization of plans and schedules, together with graphs, solids, and surfaces as well as their 3D animations. Deswik imports the data from the spatial model and allows the building of optimal production schedules predicting various scenarios.

Systems have been introduced in workstations of the group management board office, and in six collieries, and the project also covered ten deposits and ninety seams – altogether more than 580.3 million tonnes of operational resources. The following actions were performed due to the deployment of the system for deposit modelling and production scheduling:

- geological databases for individual collieries have been built and ordered;
- IT tools for scheduling and deposit modelling have been implemented in collieries;
- geological models have been developed for strategic deposits, resource parts, and mining levels of all mines/collieries;

- central strategic production schedules have been developed, relating to deposit models in six collieries;
- a model for operational strategic scheduling operations has been developed, which enables the integration of schedules at the level of the management board office,
- at the level of the management board office, it is planned to build a central database, aggregating deposit models and production schedules.

The literature provides descriptions of numerous studies on the geological modelling of deposits, e.g. (Kokesz and Mucha 1992; Sermet et al. 2017; Mielimąka 1991; Borowicz et al. 2014; Naworyta 2016; Mucha et al. 2017; Wasilewska-Błaszczyk and Mucha 2014; Probierz and Marcisz 2000, 2004, 2007; Marcisz et al. 2017, 2021; Probierz et al. 2017) and on mining production scheduling, e.g. (Dyczko et al. 2014; Dzedzej and Nowicki 2008, 2013; Gumiński 2014; Serafin 2007; Grzesica 2014; Szot 2010; Kijanka and Wróbel 2017). However, the system presented in this paper and implemented by the mining group, is a new solution, capturing in centralized IT tools the entire process related to deposit modelling and production scheduling. It is an original solution which has not yet been applied in the mining practice. It is also necessary to emphasize the large scale of the project because it covered six mines, ten deposits and ninety seams. It expresses a comprehensive attitude of the group to the quality management of the production, according to which, the products quality should be monitored and supervised at every stage of production to increase the production potential and to stabilize the coal quality.

2.4. Description of the technical architecture of the system developed in JSW

At the beginning of 1990s, Jakob Nielsen and Rolf Molich, studying the role of usability in computer applications development, published a paper *Improving a Human-Computer Dialogue*, which contained a set of heuristics, being also now an assessment basis for application interfaces and human-computer interactions. The construction of architecture systems based on heuristic assessment allowed the obtaining of feedback on the solution usability at an early stage of designing and deployment. In addition, the application of appropriate heuristics enabled use of appropriate measures to optimize the system operation. Because of the specific nature of the solution and the implementation area, the analysis focused on the following heuristics:

- Keeping consistency between the system and reality – the system had to be adapted to the user by using words, terms, and notions used in the served process.
- Enable choice, do not force to remember – due to the degree of complexity of the process which the system was to serve, special attention was paid during the implementation to such a system configuration, which would enable users to perform tasks without the need to remember individual actions.
- Flexibility and effectiveness of use – the interface should be designed so as to not create a problem even for beginning users, actions carried out most frequently should be started with a minimum amount of labor.

The technical architecture of MineScape and Deswik systems is partly based on a client-server architecture. The systems are based on centrally processed databases. For both systems the central database is a reference and not a source of transaction data for the current operation – these data are processed locally. Figure 1 presents a diagram of the architecture. The server part, apart from the Geological Database (GDB), contains Deswik FM – Deswik File Manager data sources, which is a Document Management System class solution. The entire infrastructure is subject to standard mechanisms of the Mining Group IT systems, which is the security policies for workstations as well as archiving and high accessibility policies for solutions installed in the virtual environment.

The MineScape system features a fully integrated architecture of modules, which enable modelling of the geological structure of selected production seams and qualitative parameters. MineScape also has a feature of an environment serving many users during work with graphic data, which enables saving changes in one file at the same time. The MineScape has a possibility to share projects stored on the GDB server. It is also possible to share projects stored on local discs of individual workstations, but due to restrictions resulting from the security policy, this functionality has been blocked. The GDB database is created on a virtual server and it stores projects of individual collieries.

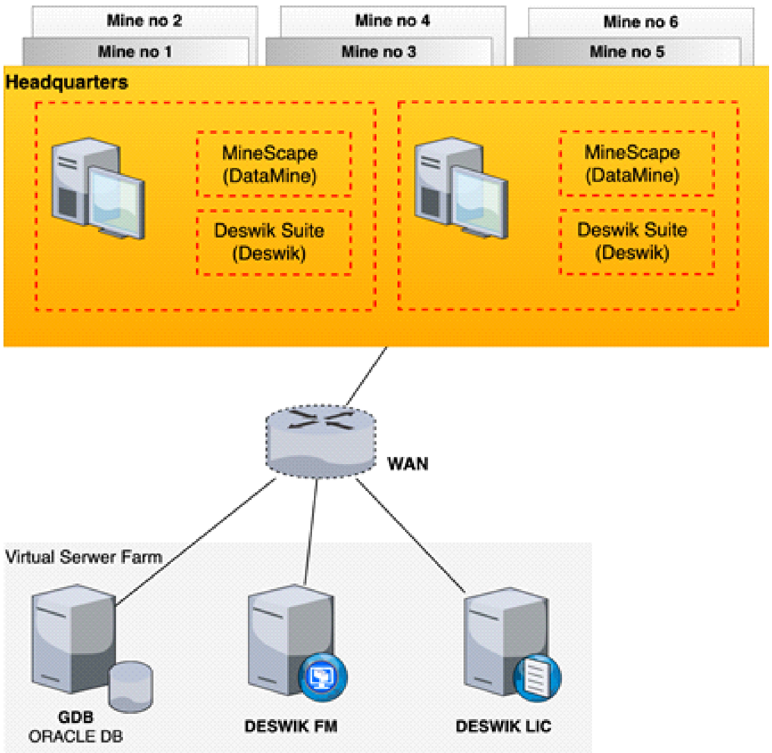

Fig. 1. Diagram of the solution physical architecture (own study)

Rys. 1. Schemat architektury fizycznej rozwiązania

The Deswik system consists of 5 modules: Deswik.CAD, Deswik.SCHED, Deswik.IS, Deswik.ADVUGC, and Deswik.FM modules. Figure 2 presents interrelations between the modules. The Deswik.CAD module ensures a three-dimensional design platform. The data collected from other sources by means of this module may be served within further deposit designing or by introducing appropriate changes and seams editions and also by introducing additional attributes or metadata helpful in the field of schedule development in the Deswik.SCHED module. The Deswik.SCHED module in turn is used to develop long-term schedules, keeping relationships and features corresponding to individual collieries characters. Priorities are set within this module as well as limitations related to accessibility of resources, which are used in the process of mining. The Deswik.SCHED module is connected with the Deswik.CAD module via the Deswik.IS module, from which it downloads the data on individual seams and workings. Based on these data, a mining schedule is next designed for

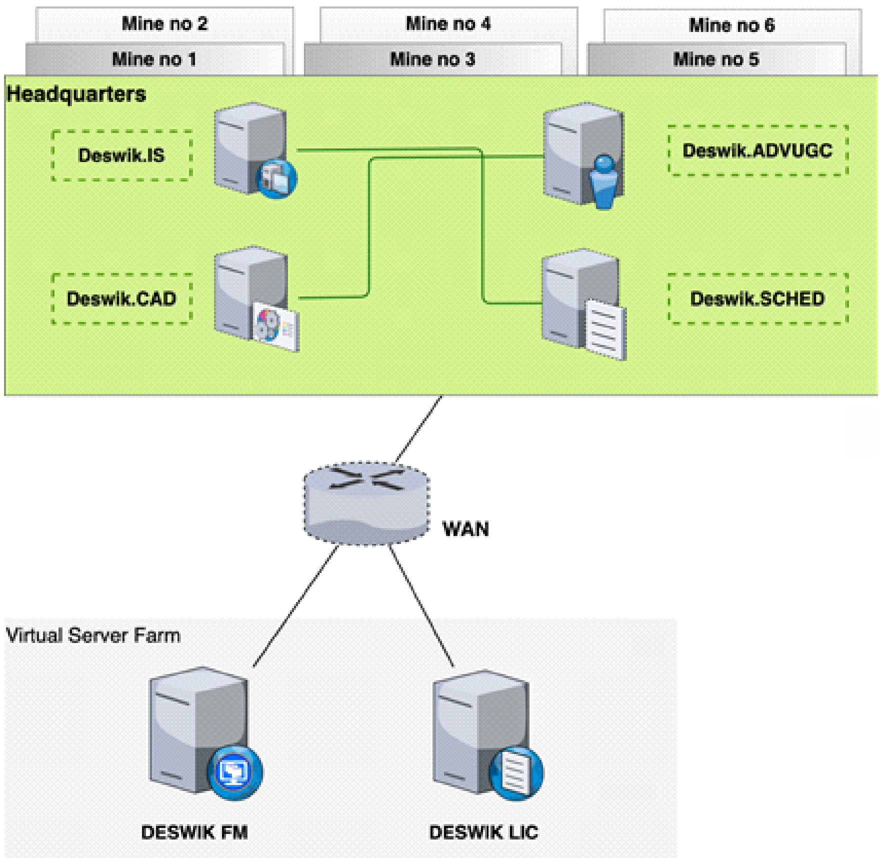

Fig. 2. Diagram of the Deswik system architecture (own study)

Rys. 2. Schemat architektury systemu Deswik each of the individual collieries. The Deswik.IS module ensures direct integration of the Deswik.CAD 3D designing environment with the Deswik.SCHED based on the Gantt chart (as an intermediating module). Complex mining processes, as well as auxiliary tasks, such as equipping the face or withdrawing the equipment, are defined within this module. The module ensures feedback in the form of a visualized schedule, which is updated on a current basis. The next module, the Deswik.ADVUGC, is used to support designing within the Deswik.CAD in the field of automation of project line creation and assigning attributes to individual seams/works under the schedule designed for a specific colliery.

The Deswik.FM module is integrated with Deswik.CAD and Deswick.SCHED, which save files and enable their use from the management board office level to create collective reports on schedules of the planned mining for the present period. Deswik.FM may be referred to as a documents repository. The module is used to manage file versions and the access to them within the present limitations. It also determines the current status and shows the history of selected files.

2.5. System configuration

Modern design supporting packages have a countless number of algorithms, from the simplest to the most complicated. From the moment of geological work until the output transport, an integrated system of algorithms ensures the possibility of the continuous calculation of deposit resources, controlling the state of works, and numerous other tasks, with permanent accessibility to a friendly graphical environment. The presence of algorithms and their complexity enables control over the time necessary to achieve the intended modelling objectives (Kapageridis 2005).

The development of mining plans is the process proceeding linearly. Information from boreholes and the geodetic data is gathered to determine the structure and to analyze the deposit quality. The gathered data are then used to develop a geological model of the deposit structure and quality, and to determine its resources based on mining limitations. Mining planning utilizes information from geological modelling to designing 3D blocks of a size enabling the scheduling of production. The amount and quality of mineral in individual blocks is estimated and taking mining limitations into account, a production schedule is then created.

The optimization of the prepared schedule usually requires creating a few alternative production scenarios. If the production process is effective integrated and linear, the amount of time necessary to prepare a single scenario will be limited. In addition, this process should be repeated, if new geological information becomes available. This is aimed at ensuring that the assumptions of the created plan reflects the actual conditions existing in the deposit. The inaccuracy of geological models can result in the origination of errors in the next steps of mining planning, which in turn can end with an unexpected increase in the cost and decreased revenue of mining activity (Wilkinson 2010).

The MineScape system implemented in the JSW SA uses an Oracle database in the Oracle 12c version. The server of MineScape projects is set on the Windows Server 2012 R2 system, providing the following services:
- MineScape Design File service,
- MineScape Design File Monitor service,
- MineScape Monitor service.

Within the GDB database configuration on Oracle, one database was established for all users, broken down to GDB projects for each colliery participating in the project. The server of MineScape projects was started on a virtual server and made accessible to all MineScape system users. Servers of Oracle database and MineScape projects were connected to the corporate network of the JSW Capital Group, users are authorized in accordance with the Group corporate security policy, and it is managed by the IT section.

3. Integration of JSW SA production line management system with the Group business systems

The software for production planning and operations scheduling is now subject to more and more dynamic development resulting from the Industry 4.0 idea and from the progress of technology (Palka and Stecuła 2018, 2019), both in terms of modelling itself and the visualization. The visualization of cutting machine movement, during which we follow a series of optimized (movement related) diagrams, is no longer something extraordinary. Such diagrams, connected in a 3D environment and visualized with appropriate time synchronization, provide an almost real picture of the minerals mining process. A set of tools is applied to any movements of objects in various ways causing the software environment to be fully interactive (Kapageridis 2005). The geological-mining software, utilizing the dynamic development of IT technologies, is subject to changes that are typical of the entire sector, which in relation to the applications in the mining industry means the following trends (Jurdziak and Kawalec 2011):
- concentration of the potential of companies delivering software to the mining industry;
- expansion of the scope of actions covered by computer assistance – development of new algorithms for the modelling and optimization of selected processes, implementation of new IT technologies, development of new IT tools;
- integration of proposed solutions – replacing tools serving 'island' processes with comprehensive solutions to support documentation to analyze and optimize the entire chain of value creation in a mining enterprise;
- avalanche type growth of increasingly diverse data, gathered and processed with dedicated specialized software;
- construction of IT environments to manage the process of specialized data processing to ensure continuity and digital security of computer support on the scale of served mining corporation.

The production management in a mine, like in any other enterprise, actually consists of a continuous decision making process in which the arising issues are resolved (Dyczko 2009). Under the mine and mining process management conditions, the phase of decision preparation on starting the mining has a crucial importance for its rationality and pertinence. This means that the necessary information on the nature of mined deposit, as well as on factors limiting the mining is gathered, and on the cost side of the carried out technological process – in other words the entire information process must be subject to INTEGRATION.

3.1. MineScape system integration with the JSW Group IT infrastructure

The integration of the MineScape system with IT systems operating in the JSW Capital Group was one of its implementation stages. The system had to be integrated with three systems: Geolisp, ArchiDeMeS, and Deswik.

A dedicated function was created in the Geoslip software, which enables the dumping of information from roadway profiles and selected longwall profiles necessary to build a stratigraphic model in MineScape. This function allows exporting necessary data in the form of two .csv files (coordinates and lithology) in a determined format, enabling the loading of these data to GDB database tables (Borehole Data, Lithography and Stratigraphy). During the loading of data to the GDB database, the data are subject to standard verification processes and are treated in the database as boreholes. The other required data (e.g. isolines of 3D topography, 3D geodetic points, fault traces, lines of narrowing or splitting, wash out zones etc.) are imported using standard mechanisms such as the preview and/or import of data from the AutoCAD format. The MineScape system also exports the data to the Geoslip system via the AutoCAD format. It applies to such data which are model derivatives, and are required for the visualization needs in seam and level maps. These include isolines of the roof, floor, and thickness, and also traces of modelled faults.

With respect to the ArchiDeMeS, it is necessary to emphasize that in the Group mines, the practice so far consisted of manually entering the results of analyses, obtained on paper or electronically (using e-mail) into a spreadsheet file or in exporting the data from the ArchiDeMeS software to a text file and further processing until obtaining the required data format. The GDB database is the target repository of the data, checked and approved by geologists, originating from the qualitative analyses of coal. A validation vocabulary has also been developed, aimed at the final verification of the values of qualitative parameters.

Because of this, the procedure, considering the use of ArchiDeMeS database, consisted of the following steps:

- building an SQL script which unloads the indicated data from the database structure to a text file of defined format;
- loading the data to an XLS format;
- data checking and approving by a geologist;
- loading the qualitative data to the GDB.

Because of a high degree of complication in the procedure and the redundancy of data between the ArchiDeMeS system and the MineScape (GDB), it was necessary to switch the method of geological qualitative data storage (borehole information, channel samples, underground findings) to the GDB system.

The processing of qualitative data acquired for the needs of the geological model has been simplified based on an agreement with the testing laboratory, that is the MineScape system was integrated with the LIMS (Laboratory Information Management System) class system, supporting processes of deposit and product quality testing management, the laboratory functioning, and distribution of deposit and product test results in the JSW Capital Group.

The Deswik company system has an interface allowing the import of data from the geological model of the MineScape system. Along with the update of the MineScape software, the possibility of exporting the model to the format indicated by Deswik (GoCAD) has been ensured, which enables the transfer of data from the MineScape geological model directly to the Deswik format (data required by JSW on the structure and quality of the deposit). In the field of model data, for the needs related to mining designing and scheduling, the MineScape system enables the preparation and making of the stratigraphic model available in the standard MineScape format – Stratmodel.

Table 1. Integration of Deswik software

Tabela 1. Integracja oprogramowania Deswik

Business area	Software	Description of actions within the Deswik integration
Production planning	THPR	◆ configuration of schedule report to match the required input data ◆ studying options of direct import to the THPR system ◆ specification of requirements related to the process, and preparation of the data to import the current production results from external sources (such as the SZYK database or surveying data)
Geology	MineScape	n.a.
Surveying, geology	AutoCAD	◆ development of processes map to import geological and surveying data from the existing AutoCAD files ◆ development of processes map to export drawings with mining designs to the existing AutoCAD files
	Subsidence	◆ configuration of schedule report to match the required input data ◆ configuration of Deswik.CAD report to export the design coordinates of longwall faces (blocks)
Control	Hyperion	◆ configuration of schedule report to match the required input data
Ventilation	Aero	◆ configuration of schedule report to match the required input data ◆ testing the results of ventilation modelling import with regard to displaying in own software
Geophysics	Hestia	◆ configuration of schedule report to match the required input data ◆ testing the results of rock bump occurrence points import with regard to displaying in own software

3.2. Deswik system integration with the JSW Group IT infrastructure

Table 1 presents the list of systems with which the Deswik production scheduling system had to be integrated. In addition to the list of systems, the following table comprises business areas (to which specific integration applies), the target software (integrated with the Deswik software), and the description of actions in the field of individual integration cases.

Conclusions

The developed technical architecture of the prepared solution presented in the paper is supported by two systems – MineScape, used to model the deposit, and Deswik, enabling production planning and scheduling in a multi-plant mining enterprise. The developed IT architecture allowed the implementation of the system for mining production management and planning in the JSW SA.

In the developed data model, the system is based on two sources – Geological Database (GDB) and Deswik.FM. The physical architecture presents a simplified client-server model in which there are no complicated interfaces due to a low level of transactions. The entire solution is based on the software installed on workstations and the server part, which ensures access to the data (the application logic is realized by the client software). The presented architecture is simple and accessible to users; it was successfully introduced in all mines of the JSW Group.

The designing of mining and development works in 3D space performed on the basis of the geological model of the deposit, describing both its structure and quality, has been carried out in the JSW SA for three years. Within the next four years, it is planned to raise the level of data integration by the application of spatial databases storage (Krawczyk 2018). The developed mining variants are analyzed in any time interval due to the possibility to choose any operations calendar. This may be, for example, a monthly calendar broken down to days, an annual calendar broken down to months, and also a daily calendar, five-year, or twenty-year calendar, until the depletion of the mine resources. Because of the continuous updating of the information in the database and the 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 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 enables the automatic calculation of the quantity and quality of output and dirt in selected time slots, and after completion of the simulation; the automatic generation of forecast for all parameters related to the implemented mining project, such as the output quantity, amount of dirt, qualitative parameters.

The implementation and integration of quality testing processes, digital exploration of the deposit coal and its parameters, and based on that information, automated production and quality planning and scheduling, enabled the introduction of a proactive production control and the obtaining of improved stable parameters of saleable coal. Because of systems implementation and integration in the area of quality management, it is now possible 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 the development operations and mining to obtain and maintain the required levels of product physicochemical parameters;
- carry out selective mining through the control of output quantity and quality – introduction of output control with diversified parameters and selective preparation process;
- separate the product streams in terms of their quality based on determined key qualitative parameters and market demand to maximize the sales prices – in 2020, price rises were obtained for coals delivered to strategic suppliers as a result of maintaining a stable level of coking parameters of the produced coking coal;
- eliminate purchases of low-phosphorus coal from outside of the JSW CG.

The aforementioned 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 also enabled monitoring and managing the complaint processes on a current basis to minimize their financial effect.

After the implementation of the system for deposit modelling as well as production planning and scheduling, possible financial benefits can reach even as much as a dozen or so euro million, being in a way a return on the investments and design operations carried out so far as well as operating actions conducted by the company Quality Office, estimated by the paper's author based hypothetical negotiated changes of prices in the contract implementation with a key customer,. This estimate was made based on results of international market analyses carried out by the *globalCOAL* (globalCOAL 2021) containing data on the current and anticipated coal prices, market factors, and energy trends.

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CONSTRUCTION OF A HEURISTIC ARCHITECTURE OF A PRODUCTION LINE MANAGEMENT SYSTEM IN THE JSW SA MINING GROUP IN THE THE CONTEXT OF OUTPUT STABILIZATION, QUALITY IMPROVEMENT AND THE MAXIMIZATION OF ECONOMIC EFFECTS

Keywords

heuristic methods in the resolution of planning problems, geological modelling of the deposit, production scheduling, IT systems architecture, production quality management

Abstract

The effective implementation of new market strategies presents 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 the percentage reserve level of each parameter, shape the profitability of undertaken projects. The paper raises the issue of designing an IT architecture of the system for deposit modelling and mining production scheduling, implemented in the JSW SA. The development and application of the system was important with regard to the overriding objective of the Quality ProgramProgram of the JSW Capital Group, which is increasing the effectiveness of deposit and commercial product quality management. The paper also presents the required specification of the technical architecture necessary to implement systems and the actions required to integrate them with other IT systems of the JSW Group. The heuristic technical architecture of the JSW SA production line management system presented in the paper enables an analysis of 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.

BUDOWA HEURYSTYCZNEJ ARCHITEKTURY SYSTEMU ZARZĄDZANIE CIĄGIEM PRODUKCYJNYM GRUPY GÓRNICZEJ JSW SA W ASPEKCIE STABILIZACJI I POPRAWY JAKOŚCI UROBKU ORAZ MAKSYMALIZACJI EFEKTÓW EKONOMICZNYCH

Słowa kluczowe

harmonogramowanie produkcji, metody heurystyczne w rozwiązywaniu problemów planistycznych, modelowanie geologiczne złoża, architektura systemów informatycznych, zarządzanie jakością produkcji

Streszczenie

Skuteczna realizacja nowych strategii rynkowych stawia przed przedsiębiorstwami wydobywczymi nowe wyzwania, których realizacja wymaga precyzyjnych instrumentów oceny prowadzonej działalności na szczeblu kopalń, zakładów przeróbczych, koksowni, jak i hut. Instrumentami tymi są parametry złożowe, technologiczne i ekonomiczne, które wraz z marginesami bezpieczeństwa określającymi procentowy poziom rezerw każdego z parametrów kształtują rentowność podejmowanych przedsięwzięć. W artykule poruszono tematykę projektowania informatycznej architektury systemu do modelowania złoża oraz harmonogramowania produkcji górniczej, wdrożonego w JSW SA. Opracowanie i zastosowanie systemu było istotne z pespektywy realizacji nadrzędnego celu Programu Jakość Grupy Kapitałowej JSW, czyli zwiększenia efektywności zarządzania jakością złoża i produktu handlowego. Następnie w artykule przedstawiono opracowaną wymaganą specyfikację architektury technicznej, niezbędnej dla wdrożenia systemów oraz wymagane działania niezbędne do integracji z innymi systemami IT Grupy JSW. Prezentowana w artykule heurystyczna architektura techniczna systemu zarządzania ciągiem produkcyjnym JSW SA pozwala analizować rentowność procesu produkcyjnego w układzie rachunku ciągnionego w obszarze kopalń, zakładów przeróbczych i koksowni grupy górniczej największego europejskiego producenta węgla do celów metalurgicznych. Sytuacja rynku surowcowego staje się problematyczna dla przedsiębiorców, którzy muszą w sposób elastyczny dopasowywać swoje firmy do zmiennych warunków rynkowych, aby utrzymać tzw. biznesowość swoich projektów górniczych.