Innovative Concept of Production Support System for the LW Bogdanka Mine

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Abstract. The research work results, presented in the article, describe a system concerning the management of a production line in the aspect of stabilization and improvement of the run-of-mine quality and maximization of economic effects. Basing on the geological deposit model, the authors concentrated on designing mining operations and on planning production parameters. Special attention was paid to a development of the mine workings design module, the mining operations scheduling module, the module for mixing and optimization from the quality point of view as well as the module for mining operations revenues and forecasts of costs. Forecasting the production quality, planning and integration of mining processes with coal preparation processes and sales are discussed in detail. The article is ended with some recommendations of general character, including quality management at the stage of mining and production planning, quality monitoring at the stage of coal mining, and its preparation. The system is oriented onto production quality forecasting and onto an integration of mining, preparation and sales planning.

1. Introduction

An automation of production processes, implemented in the LW Bogdanka, required studies and analyses of several interconnected components. A development of an innovative concept, enabling the management of the production line in the aspect of stabilization and improvement of the run-of-mine quality and maximization of economic effects was possible due to a realization of some research projects at the KGHM Polska Miedź S.A., JSW-Jastrzębska Coal Company S.A. and the TAURON Wydobycie S.A. The developed concept is based on the Integration Platform which is a crucial component of the presented solution. As a matter of fact it is a good and convenient tool for an integration of different pieces of information, enabling a standardized exchange of data among systems built in various technologies, using various communication protocols.

An innovative approach to the management of the production line consists in a division of a deposit as regards its quality, including mineralogical and petrographic features to establish quality parameters for a preparation of minerals. In the case of hard coal this division is based on physical properties (a division into coal grades) and also on the ash and sulphur content. Coal quality has a decisive impact on its further use. The division criteria must be clearly defined [1]. If a few different mineral grades occur in the deposit, then their distribution is presented on maps and cross-sections and their amount must be calculated separately. Qualitative and quantitative features of the deposit have an impact on its economic value. The following factors decide about the economic value of the deposit:
Innovative Mining Technologies Scientific and Technical Conference (IMTECH 2020) IOP Conf. Series: Materials Science and Engineering 1134 (2021) 012004 doi:10.1088/1757-899X/1134/1/012004

- a deposit attractiveness for management determined by its depth, structure, configuration and mineral properties,
- a degree of the deposit development for management,
- a suggested method of deposit management,
- a risk related to an assessment of technical and economic conditions of mining and preparation processes as well as sales of products obtained from the minerals’ production line.

The aforementioned factors are interrelated, but it is important to remember that they are either related to the natural properties of the deposit or to the activities oriented onto its management. A design of the deposit management together with technical and economic analyses of the plant construction form the basis for a determination of commercial resources. These analyses clarify and justify the following management components:
- a choice of the deposit opening method and of its mining method,
- a determination of basic mining-and-geological parameters,
- a determination of mining and preparation costs,
- a determination of economic factors.

Figure 1 presents a classification of resources from the point of view of their economic importance.

![Figure 1. Classification of resources in terms of their economic importance](image)

The mining losses (quantitative losses) substantially reduce the deposit mining efficiency, resulting in increased expenditure on development work. The dilution (qualitative losses) causes transport and preparation costs increase. Big thickness changeability, forcing to rip the dirt to obtain the required cutting height and also a big number of dirt bands, result in increased amount of dilution which rises
costs of preparation processes. Due to an appropriate selection of mining systems and machinery parameters, it is possible to reduce the amount of dirt and thus to improve economic effects. Analyzing a dilution of ore deposits some researchers [3]-[5] concentrated on the factors which cause this phenomenon. They distinguished two types of dilution such as:

- a mining dilution resulting directly from the carried out mining operations where the dirt, situated close to the mined mineral, crumbles into pieces,
- a structural dilution, related to the nature of the deposit itself, results from a presence of individual spoil formations within the deposit.

Noppe [6] expressed an opinion that in the case of longwall mining, when cutting is carried out at the full seam height, it is not possible to avoid dirt in the run-of-mine. The sources of dilution can be divided into three groups:

- a primary dilution originating from ripping the seam roof or floor,
- a secondary dilution resulting from ripping the floor uplift or from the roof fall,
- a third-rate dilution caused by cleaning powered roof support units or mixing the dirt from drifts with the coal run-of-mine from longwalls.

In the case of underground mines Saeedi at al. [7] ranges so-called off-seam dilution (OSD) from 15 to 30% in relation to mining-and-geological conditions as well as to technical parameters of the machinery used in a given mining system.

Sources of dilution in a longwall face are presented in Figure 2.

![Figure 2. Sources of dilution in a longwall face [6].](image-url)
2. Research objectives
The research methods and tools, applied for a development of an innovative system for the LW Bogdanka, were used for confirming the fact that it is possible to achieve positive economic results of rationalizing the coal winning processes consisting in extracting less dirt, where it is geologically and technically justified. Technical and economic analysis should include basic elements which are decisive in the management of the coal production line, in particular:
- a selection of a deposit opening method and of a deposit exploitation system [8, 9],
- a determination of basic mining-and-geological parameters [10, 11],
- a determination of costs of exploitation and beneficiation processes [12, 13],
- a determination of economic indicators.

An implementation of a correct mining system and of correctly selected machinery reduces losses and impoverishment significantly. The research methods, techniques and tools presented in the article include:
- an expert assessment of Polish and foreign literature [14, 15, 16],
- mathematical modelling,
- probabilistic modelling,
- statistical analysis,
- assessment of economic efficiency [17].

3. Concept of production support system
The innovative concept of production support system is based on a holistic and integrated approach to the movement of machinery and people, flow of production, transport and service tasks in terms of production processes planning, organizing, controlling and inspecting. Basic tasks of the system, to be used in an integrated information environment of underground mines, comprise:
- designing and scheduling of mining projects based on a numerical deposit model together with an application of parametric methods for designing mine workings, transport systems and the infrastructure, forecasting production rates and costs as well as with an optimization of economic parameters,
- planning and organizing the production line, service, transport including employees, equipment, machines and materials,
- coordination and control of production, transport and service tasks as well as a circulation of documents,
- management of full life cycles of production projects and equipment,
- control of the production quality,
- integration, gathering, processing and reporting the data registered in the economic IT environment and technical systems,
- optimization of raw materials storage, transport and preparation based on algorithms and models of advanced process control (APC).

The concept of the production support system is oriented onto improving the main processes, identified within the numerical deposit model (NDM), such as:
- geological work designing and performance,
- interpretation and documentation of geological structure of the deposit together with its register of resources,
- support of mining and production planning,
- support of coal mining processes.

An implementation of a specialized tool (CAD) to create a numerical deposit model is the recommended solution. Linking of the Geological Database (GDB) and the Geological Deposit Model (GDM) with the Central Data Warehouse enables a bidirectional exchange of information with the
Map Data (MAP) area, making the deposit model available to the Mining Operations Scheduling (MOS) area. Figure 3 shows a schematic diagram of the system structure.

![Diagram of the target solution in the numerical deposit model (NDM) area and its links with other areas of the production support system [18].](diagram.png)

The Geological Database (GDB) is designed as an element of the Central Data Warehouse. Full geological information includes:

- lithographic profiles of surface boreholes, underground boreholes and mine workings,
- results of coal quality sampling (qualitative, chemical, physical and physiochemical data as well as data related to an analysis of coal washability),
- hydrogeological information containing measurements of the water table height, of the water inflow, of the water chemism and of underground water radioactivity,
- results of geomechanical tests in penetrometric boreholes.

The Geological Database (GDB) enables to record and service geological samples together with bidirectional integration with the Map Data (MAP) area.

4. Geological deposit model

Two methods were used for geological modelling: stratigraphic modelling and block modelling. Various sets of rules were used for different seams, enabling to develop separate models in various locations and in various ranges of the deposit stratigraphic profile. The outcome consisted of a stratigraphic table and a set of surfaces (grid), representing all the strata and stratigraphic surfaces selected for modelling. The data on seam qualitative parameters and dirt bands were processed in a similar way. As far as a development of grid models was concerned, several interpolator methods such as: finite element, inverse distance, kriging, nearest neighbour and triangulation methods were available.

The following data were processed:

- lithostratigraphic sequences,
- fault strike lines,
- profiles documenting exposures of lithological and stratigraphic strata,
- point findings of individual stratigraphic surfaces,
- graphical elements, imposed by the user, forcing certain geometrical parameters of the model.

Due to the tectonic structure complexity, modelling of faults is an important element of the deposit
model functionality. Faults are created in the system basing on point findings. The coal seams splitting is also modelled. The modelling of qualitative parameters (calorific value, sulphur content, ash content, moisture content, density etc.) is one of basic requirements. The developed qualitative models are used to calculate resources as well as for the quality planning processes.

Hydrogeological data are used in the deposit model to create thematic point maps. The data are used to develop models of the water table position in the selected water-bearing levels and to generate 3D visualization of water reservoirs.

Calculations of the deposit resources are carried out within the management system. Resource reports are produced on the current deposit model. The geological data and industrial elements of the model are visualized. The solution, presented in the concept, utilizes the Central Data Warehouse to report and make the required geological contents available. Visualizations are saved to .dwg files and they are also printed and exported to other data exchange formats e.g. pdf.

5. **Mining operations designing and production planning (MOS)**

The MOS system supports the process of mining operations designing and scheduling as well as the process of production scheduling with a possibility of quick updating, carrying out simulations and integrating a selected area with other components of the Production Support System. These processes are based on the geological deposit model, described in Item 4 of this article. The MOS area is a crucial activity in terms of short- and long-term planning of operational activity, planning of costs, investments, repairs etc.

The target process of production preparation and planning starts from the market analysis in terms of the possibility of selling individual products group. Figure 4 presents the diagram of the MOS system structure, containing four models:

- mine workings designing module,
- mining operations scheduling module,
- quality optimization module,
- module of revenues and costs forecasts of mining operations.

The process of mining operations designing, production planning and mining operations scheduling provides feedback to other management areas enabling to obtain final products of specified quality parameters. Mine workings designing module in the MOS enables a better understanding of the strata deposition and the course of planned workings (type, function, cross-section). It contains complete information on the deposit. It is integrated with the numerical deposit model. Mining operations scheduling module in the MOS plays an important role, as it enables to generate and analyze several variants aimed at finding the optimal solution in terms of quality and quantity of the products. In this case the speed of responding to changes in the deposit geological exploration is significant because it requires an update of designs and schedules. This module, combined with the preparation and sales support system, generates the data indispensable for forecasting revenues and costs of mining operations. The module for mixing and optimization, in terms of quality, is responsible for defining qualitative objectives in conjunction with quantitative objectives. This module provides a tool for scheduling mining operations. The MOS also includes the module for mining operations revenues and costs forecasting, which is closely related to the mining operations scheduling module. It provides the information on unit costs of individual mining operations and on the liabilities resulting from mining operations. Such an approach enables to obtain a complete and reliable assessment of economic-and-financial efficiency of a mining operation under analysis.
Figure 4. Diagram of production designing and scheduling system in terms of quality and links with other areas [18].

6. An integration of planning processes on the mining side with processes of coal preparation and sales
The concept of the process of a mining plant production planning and controlling, presented in the article, responds to the market demand and intended sales in individual product groups. Such an approach causes an urgent need of controlling the run-of-mine quality.

In accordance with the presented concept of the production line management the broadly understood quality area is linked to all the operational areas of a mine (Figure 5).
The integration among individual elements of the production system is extremely important because of the system functionalities and the measuring infrastructure. The production reporting area is supplied with information on the quality of semi-products and products. The quality management, at the stage of mining and production planning, is closely related to the solution developed for mining operations scheduling. The preparation and sales planning is combined with the quality control system. In such an approach the forecast of raw coal quality is an integral part of the mining operations schedule. Developed variants of mining plans may be optimized in view of satisfying different objectives: qualitative, quantitative, cost etc. Presenting the management of the run-of-mine production line, it is worth highlighting quality monitoring at the stage of coal mining and its preparation. Some corrective and preventive measures should be implemented in the case of deviations from the planned values. The system enables continuous monitoring of coal quality parameters. Results of all the measurements are transferred to the SCADA system and then to the acquisition platform of the data repository. A quality controller function relies on analyzers installed on belt conveyors. Due to such a function it is possible to control a realization of the quality plan, being an inseparable part of the production schedule. The recommended solution results in reducing the frequency of manual sampling in favour of using a continuous quality measurement system and making the results available in the production reporting system.

7. **System for production quality forecasting enabling integration of mining, preparation and sales planning**

It is an automatic system enabling to gather data from sensors installed on belt conveyors in various places of the run-of-mine haulage from the longwalls and from the preparation plant. Figure 6 presents the components of this system and their links with other production areas under analysis.
The quality management at the stage of preparation and sales planning specifies the required quantities and qualities of raw coal to meet the production assumptions related to commercial products. These requirements are transferred to the mining operations designing and scheduling system. The SCADA system collects the information from individual quality parameters monitoring devices and visualizes it in real time. The last stage of the quality control process consists in taking qualitative samples of saleable coal. Quality control tasks comprise monitoring of the production quality and quantity to ensure the quality level consistent with the commercial offer. The implementation of the coal production line management system may require an expansion of the existing IT network at the LW Bogdanka Mine, including the SCADA system as well as a purchase or a modernization of workstations.

8. Summary and conclusions
At present the coal mining sector experiences serious problems due to rather low prices and due to the European Union policy oriented onto a decarbonization, so it is important to maintain high flexibility of each mine in the context of products range and production costs. A pragmatic approach requires an...
implementation of adaptive planning mechanisms and techniques aiming at optimizing the operational activities. A capital intensive nature of mining processes, combined with long planning horizons and a big inertia of the production system, make a quick reaction to changing coal prices very difficult, because each scenario must be planned in advance. In many cases it is more a kind of a forecast than an exactly scheduled plan. It also concerns the methods of operational activity improvement, which is a long-lasting process. In this context a continuous optimization of long- and short-term plans becomes a must [19].

In general, the production support system, presented in the article, like any IT solution, is a tool enabling to facilitate and improve the management of the coal production line suggested for the LW Bogdanka. An implementation of a full PDCA (Plan-Do-Check-Act) cycle, based on continuous gathering of data, provides measurable effects. The concept of the IT system assumes an automatic calculation of the quantity and quality of the run-of-mine as well as of the dirt during selected time intervals. After a completion of simulation processes an automatic forecast is generated. Basing on the example of the LW Bogdanka, it was possible to determine an impact of qualitative losses on the efficiency of the coal mining operations. Economic effects undoubtedly depend on qualitative and quantitative criteria. Positive economic results can be reached at a relatively small cost, if the coal production support system is implemented. The Integration Platform is a central element of the system, being a reliable tool of information integration, enabling a standardized exchange of data among systems built in various technologies or using various communication protocols. The Integration Platform, suggested for the LW Bogdanka Mine, uses the Service Oriented Architecture (SOA) technology. The Technical Data Warehouse is a component of the Integration Platform which gathers the data from industrial automation systems. The data transfer from the control systems to the Technical Data Warehouse, by means of the Open Platform Communications Unified Architecture (OPC UA) standard, is a key component of the system. However, the most important component of the solution is the Support System for Mine Operations Maintenance. An effective analysis of information, gathered in the system, can substantially improve the quality of management decisions. It is recommended to build the Centre for Advanced Data Analysis (CADA). The mechanization and automation degree of basic processes, carried out in the mine, forces a necessity of combining production management and reporting areas with the area of machinery and equipment maintenance. This operation is fundamental from the point of view of the Total Productive Maintenance (TPM). An implementation of mechanisms, making the data available from the SCADA environment to the Manufacturing Execution System (MES), Computerized Maintenance Management Systems (CMMS) etc. are crucial factors that condition the entire solution effectiveness. The concept of building a decision support system in the field of production activity, using IT solutions and production monitoring, is one of the LW Bogdanka strategic objectives oriented onto building the Intelligent Solutions Mine.

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