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The construction of integrated production management systems in mining companies based on the experience of the 'Turów' brown coal mine (Poland)

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The paper presents the comments on the advantages of implementing an integrated system of managing mining exploitation in hard coal mines, as well as the comprehensive integration of information on the process of deposit exploitation with economic data, so as to achieve an optimum technical and economic effects.

The principles of constructing the production management system have been presented, thanks to which the management boards are provided with reliable technical and economic information on a mining company via information technology.

The strategic direction of a company's operation may currently be verified according to the external conditions that change over time (the information on the deposit, *force majeure* events, changing expectations of customers, etc.).

Introduction

The basis for construction of the integrated production management systems in mining companies is the Integrated Information Management System, the principles of which were presented for the first time during the conference 'The optimization of useful mineral output using information technology techniques' (Kaczarewski, T. and Kuś, R. 1999). It combines the elements describing the deposit and technological data.

The Geological and Drilling Company has developed the principles of collecting, sorting and processing information concerning deposits using IT tools. The originality of the Integrated Information Management System [IIMS] is its openness to integration within the system of the existing and tested solutions used for managing of highly specialized services. Thus, this is a merger of information on the structure, the quality of deposit and its geometry with the computer applications used, e.g. for analysing the deformation of ground surface due to mining activities, stability of slopes in strip mines, the hydrogeological models of the deposit, and the like. The IIMS is open to the expectations of the users that cannot be defined nowadays, which however, may appear along with the development of processes, measurement methods, requirements of the recipients, or environmental needs. The trials carried out in Poland in the 90s by the KGHM 'Polska Miedź', the 'Belchatów' Brown Coal Mine, as well as the Rybnik and Nadwiślańska Mining Partnerships, proved that such conditions have not been met by the solutions proposed by such companies as, e.g. Mincom, DataMine or Maptek, due to the high level of integration of the proposed solutions. In the solutions proposed by the aforementioned companies part of the information is managed by the system, which results in lack of control over the separation of the interpretation of facts done by the operator and the system. In the Polish mining sector, a principle of personal responsibility for the results of measurements and their interpretation is valid, especially as refers to the surveying and geological information. The author's previous attempts to apply one of the above-mentioned pieces of software in the 'Murcki' Coal Mine were a failure, especially due to a very complicated tectonic structure of the deposit. The experience gained, as well as the practical knowledge of the requirements to be fulfilled by the solutions applied in geology and mining resulted in formulation of criteria (Karaczewski, T. and Kuś, R. 1999) that condition the implementation of the system. The subsequent trial has brought a success, as we have based ourselves on a *modular solution*, where interpretation of facts belongs completely to an expert geologist, land surveyor, or miner.

The basic principles we dwell upon currently while undertaking any project for deposit management are as follows:

- all the information is collected within any given relational database
- data is processed to create a graphical form thereof in a 3D environment, as all of the information concerning the deposit structure constitute spatial elements
- the end products are allocated the forms required by government department regulations, standards and an investor's individual requirements
- computer programs are used that ensure openness of the system, have the capacity to be developed and the option of being extended by adding on elements that it had not been possible to anticipate at the point of creating the design project
- segregation of objective facts (the results of exploratory borings, the results of measurements, etc.) from the interpretation thereof (structural and qualitative models, the results of geostatistical analyses, maps of reserves)
- creating the design by specialized personnel at several work stations (graphical work stations) operating as part of a network.

The principle is the openness of the system to the

constantly changing environment and the expectations of the users. The schematic flow of information within IIMS has been presented in the flow chart below (Figure 1):

The digital geological database constitutes the basic source of information used during creation when applying computerized techniques for documenting useful mineral reserves that fulfil the requirements of the binding Polish regulations. Thanks to its openness, the Integrated Information Management System established based on the digital mining and geological database was the first successful trial to implement a numerical solution for geology in Poland. This took place in 1994 at the 'Halemba' Hard Coal Mine in Ruda Śląska, and further on at the 'Jan Kanty' Coal Mine in Jaworzno, the 'Murcki' Coal Mine in Katowice, and the 'Kuźnica Warężyńska' Filling Sand Mine in Dąbrowa Górnicza. All of the works constitute innovative solutions in Poland. Their implementation opens up new possibilities with regard to managing mineral raw material resources and optimization of the mining output. The geological documentation drawn up using new technologies may be supplemented on a daily basis with information stemming from ongoing mining work and exploration work. This can also be verified by inputting specialist analyses and expert evaluations concerning the structure and quality of deposits, the hydrogeological conditions, and the geotechnical hazards. Furthermore, this creates greater possibilities for individual interpretation of facts by facilitating the recording of several variants of a solution for a specific geological problem, thus creating the conditions for selection of the preferred solution by the author (documenter?).

The system has been implemented in a broadest version at the 'Turów' Brown Coal Mine (Figure 2). At start-up the project staff possessed the data solely in the form of maps, specifications in tables, and test results—all of it in analogous versions. The data became the basis for creation

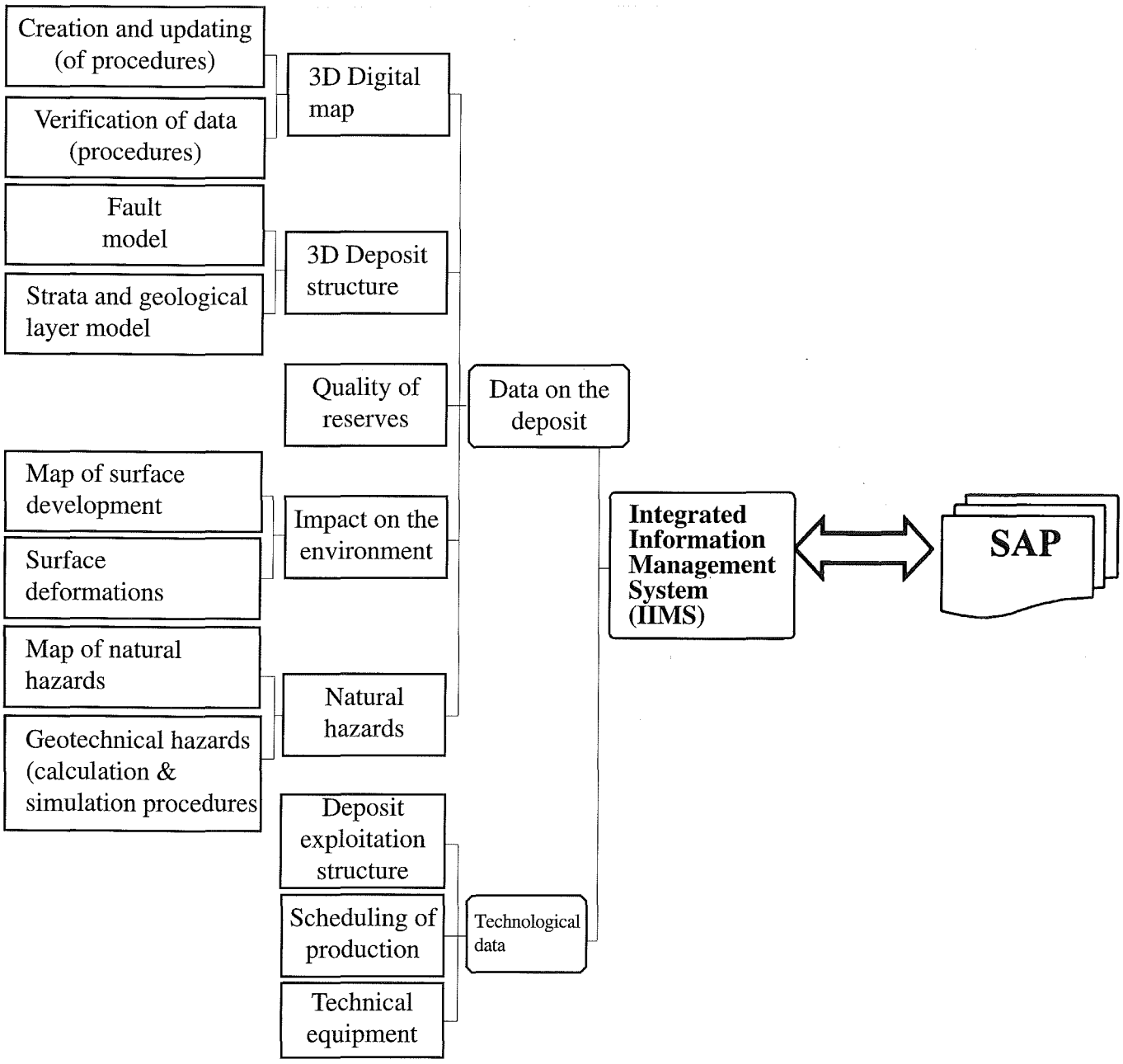

Figure 1. Schematic flow of information within the Integrated Information Management System

of a database of about 7 million records, and further on—the Integrated Information Management System.

The 'Turów' Brown Coal Mine occupies the area of 22.3 m², with the surface area of the external storage yard equal to 18.5 m², which makes it the second-largest strip mine in Europe. The output of 11.2 million Mg as well as 49.2 million Mg of strippings gives the mine the second position in Poland. The first position is occupied by the 'Belchatów' Brown Coal Mine. The coal excavated at 'Turów' ensures the generation of 8% of electric power in Poland.

The proper construction of the database and the elaboration of the appropriate connections between computer applications enables each mining company to set up an optimal production management system taking into account not only the specific characteristics of the given sector (hard coal, brown coal, copper, rock raw materials), but also the individual characteristics of a particular mine.

The Integrated Information Management System ensures the integration of all the elements connected with the description of deposits both directly (data on the deposit structure and its quality) and indirectly (surveying and technological data), which makes it possible to select the optimal variant of opening out and exploiting the deposits. This is particularly important when the deposit has a complex geological structure and untypical technological solutions needed to be applied.

For each mine the principal matters requiring optimal solutions with regard to technical as well as economic and financial aspects are the following:

- ensuring the appropriate level of output of useful minerals with stabilized quality parameters
- in open pits—removing the overburden to such an extent as to facilitate the progress of the deposit exploitation without running ahead of schedule to an excessive degree, which would lead to
  - a rise in technological (production) costs
  - increase in the range and costs of taking over land for mining purposes
  - an increased scope of taxes and fees connected with land management
  - increased impact on and hazards for the surrounding environment
- dumping of waste rock—determined on the basis of the deposit exploitation level hitherto attained, progress in the extraction of useful minerals and the arduousness of natural conditions
- the precise forecasting of operating costs connected with the solutions for the above issues.

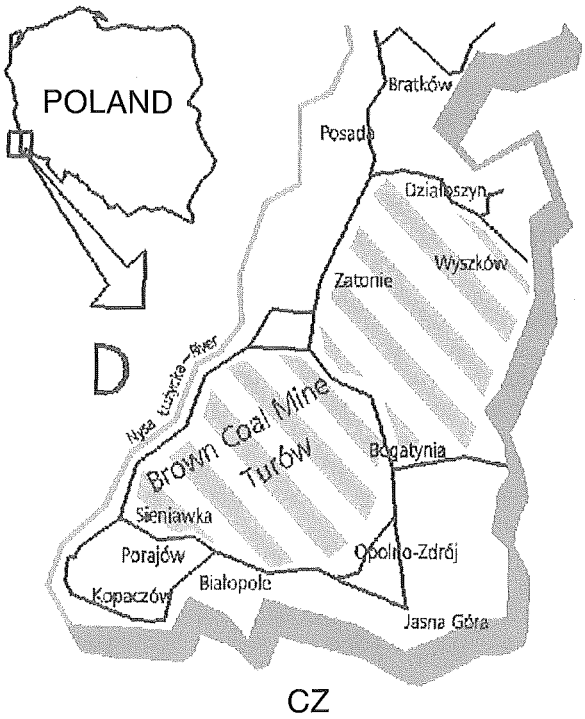

Figure 2. The map of the 'Turów' Brown Coal Mine; D-Germany, CZ-Czech Republic

The complexity and the very broad scope of source information relating to these matters means that finding effective optimal solutions requires support from IT systems. It is probable that in the near future it will be necessary to more or less constantly plan, analyse and adjust the deposit exploitation process with respect to the changing circumstances in the mine and the external conditions. *In order to ensure that optimal decisions are taken, it is necessary to carry out and analyse numerous frequently changing solution variants.*

Each mining company has specific technical, economic and organizational matters to deal with and it solves such issues on an ongoing basis. It is possible to do this using the professional skills and experience of the technical staff and management, however, right from the start assuming their imperfection due to time limits and the consequential limited access to the full scope of information. By using IT tools it is possible to obtain a variant-based analysis of individual technical solutions extended to include information on the economic effects of these variants. Thus these types of analyses are not only based on the knowledge and experience of the team of engineers, but also there is full awareness that individual variants have been elaborated using all of the available information sorted within a *relational database.*

On implementing the *Integrated Information Management System (IIMS)* within one mining unit information on the financial consequences connected with particular solutions subject to analysis are *always* finally obtained. *This constitutes the obvious and anticipated effect of any economic undertaking.*

In the 'Turów' mine it has been operating with the full awareness that in order to ensure the optimization of production, information flowing to the mining technology department must be fully integrated. Its preparation is the responsibility of technical personnel documenting the geometry of the mining excavations, the structure and quality of the deposit, the natural hazards and the impact on the environment. The following computer applications play a key role within the *Integrated Information Management System (IIMS)*: the geological and mining computer applications supplied by the firm GSMI developed for the purposes of the South African mining industry and the SoftMine program suite developed for the specialist purposes of the Polish mining industry. The aforementioned applications do not solely facilitate the planning of the daily, decade, monthly and half-year production plans, they also facilitate strategic planning for periods freely defined by the user until reserves are exhausted. A significant feature consists in the possibility of performing variant-based analyses of solutions and verifying a given deposit reconstruction concept against data obtained from ongoing mining work, natural hazards arising as well as changes in the market conditions. Analysis of experience around the

world indicates that the ultimate parameter constituting a decisive factor proving the appropriateness of the selected technical solution is the profit generated by a particular mine in relation to a company as a whole and also in relation to individual production sections.

The general characteristics of information utilized during the process of designing and scheduling production based on the example of the 'Turów' brown coal mine

In order to proceed to the stage of designing and scheduling of the mining output, the structure and geometry of a deposit, as well as geometry of the mining headings must be modelled first. The information used during the process of designing and scheduling may be divided into two groups:

- information collected in the geological database
- graphical information to produce digital maps and models.

The geological database

The database contains tables configured and filled in with data by users and tables created by the existing software. All of the tables are updated on a current basis by the relevant departments of the KWB Turów mine within their areas of authorization.

The database contains information on:

- the geological structure of the deposit
- the co-ordinates of the exploratory bore-holes
- the co-ordinates of the fault ascertainment points
- the results of the measurements of the monitoring and measurement systems
- the coal's quality parameters
- the hydrogeological parameters
- the geological-engineering parameters
- the size of reserves, etc.

Digital maps and models

This group of data includes:

- structural models of the deposit
- a mining map of the workings
- models of the planned method of opening out and exploiting the deposit
- structural models of the working levels
- models of the thickness of the working floor and the thickness of the useful minerals in the floor
- models of working floor quality.

Some of the sources of information mentioned above fall outside the remit of the Mining Technology Department, which is responsible for designing and scheduling production. This means that the effective exchange of information is essential and this is ensured by *IIMS*.

The structure of information flows during the process of designing and scheduling production

Each of the mine's departments is equipped with the necessary computer hardware. Communication between individual departments is facilitated by a network that connects them up with each other and also links up each department with the database. The information access principles are defined in such a way as to ensure information is used and modified solely by the persons authorized to do so.

The database is the main tool driving information flows. The information contained therein is used during the process of generating source materials for designing and scheduling production and also during the designing, scheduling and selection of the optimal variant for cutting the deposit.

The Geological Department uses the information contained in the database to elaborate models of the deposit structure. These are updated as new information on the deposit flows in. Current models are stored on the server, which means that the other authorized mine departments also have access. A digital mining map of the workings is also available on the server and this is updated monthly by the Surveying Department. The described sources of information are utilized by the Mining Technology Department. On the basis thereof, models of working levels, structural maps of working floors, models of working floor thickness and of coal thickness in working floors are created. The Mining Technology Department has access to these models and these are utilized to draw up mining designs and schedules, from which the optimal extraction progress variant is chosen with the dedicated procedures being applied. The information concerning particular designs and schedules is stored in the database, which facilitates the rapid analysis of results and consequently the choice of the optimal variant.

Production design and scheduling procedures

In order to determine the quantity of useful mineral and waste rock output for individual floors, geological information needs to be correlated with the structure of the planned method of opening out and exploiting the deposit. The principal type of information at this stage pertains to the contents of the useful minerals and the adjacent rock in the working floor, the quality of the deposit and its location. The Mining Technology Department obtains this information with the help of the I/Mine suite supplied by the firm, GMSI and SoftMine provided by the firm, PRGW Sosnowiec, the development of which took into account the specific deposit extraction conditions.

At the first stage a geometrical model of the planned method of opening out and exploiting the deposit arises. This consists of models of the existing and planned mining excavations. The mine workings are usually linked to the working floors. The models of the surfaces of the floors are elaborated on the basis of the mining map of the mine, structural and qualitative models of the deposit and the designated exploitation limits. Data for each surface of the level are inputted into the design dgn file of the MicroStation program. Modelling is carried out using Modeller applications from the I/Mine 2000 suite in the MicroStation graphical environment. The model is updated by the Mining Technology Department based on new information supplied by the Surveying Department and the Geological Department.

Thanks to the IML batch program operating within the Modeller application, models of the thickness of individual seams within working floors are elaborated on the basis of existing geological models and levels. Subsequently, these are combined to form an overall model of the thickness of coal in the floor.

During the next stage, the qualitative parameters of the useful minerals in the floors are modelled. The input data for these models and the results of the sampling of bore-

hole cores are collected in database tables. The data aresobtained using the 'Jakość' ('Quality') program, which is an element forming part of the SoftMine PRGW Sosnowiec suite. It collects data on the values of quality parameters from databases and calculates their weighted averages for the working floors. The program transfers the results obtained to the MicroStation graphics environment. On the basis of the calculated weighted average parameters that have been transferred to a graphic format and using the I/Mine Modeller application a digital model of the selected qualitative parameter of the coal in any given floor is drawn up.

Digital structural maps of working levels form the basis for the process of designing and scheduling production. These facilitate the analysis of the geological structure of a working floor as well as the production design process based thereon. Maps contain certain information concerning the geological structure and production information.

The geological information contained in the maps includes the following:

- the lines of intersection of faults on levels (the intersection of the fault model with the model of the level as per the I/Mine Modeller application)
- the lines of intersection of floors and roofs of individual seams within levels (the intersection of the seam models with the model of the level as per the I/Mine Modeller application)
- the isopachous line of working floors
- the isopachous line of useful minerals in floors.

The production information on maps consists of the following:

- the isohypse of working levels
- existing mine workings
- planned mine workings.

Exploitation is designed within the MicroStation graphical environment using the Mine Design application forming part of the CadsMine suite supplied by the firm GMSI (South Africa). The design objective consists in the division of the deposit into working panels, within which production is to be scheduled. During the design process each floor is divided into working panels with central lines. The working panels are determined by the range of excavation and the assumed shortwall width, whereas the central line is determined by the direction of excavation within a given panel.

The information prepared and sorted thus make it possible to schedule production.

At the start of scheduling, the directions of excavation that have been defined during the design process are confirmed using the Scheduler application from the CADSmine suite and the sequence of extraction is defined. This information is inputted into the internal database. The length of the shortwall depends on the duration of exploitation and the progress of work. The time internals for mining are defined in scheduling calendars, separately for each floor. During the creation of calendars the inputted time intervals are supplemented by information concerning the progress of mining equipment and breaks due to maintenance. The average progress of a particular piece of mining equipment operating on a specific working face is inputted. Maintenance breaks are defined in accordance with the maintenance plans. As a consequence, the panels that have arisen during the design process are divided into shortwalls on the basis of the defined parameters.

The plotting of shortwalls is performed separately for each level in separate design files. The shortwalls are visualized as traverses in the design files in the MicroStation graphic environment. The shortwalls plotted in the manner described above contain the symbols and the date on which mining in a given shortwall commenced, which facilitates their identification by the Reserver program.

The Reserver program calculates:

- the volume of the shortwall
- the volume and mass of the coal in the shortwall
- the qualitative parameters of the coal in the shortwall: the moisture content of coal in the working state (W^r), ash in the dry state (A^d), ash in the working state (A^r), total sulphur (S_t), the calorific value in the working state (Q_l^r).

The models of the thickness and quality of the useful minerals in the floors is used to carry out the above calculations.

Using the Reserver program the information on the shortwall size is combined with the relevant models. The program makes it possible to perform calculations on models and the calculation results are inputted into the databases. The work with the program consists of two stages. In the first stage, Reserver extracts the co-ordinates of the vertices of the element representing the shortwall from the graphics file and stores them in the database.

In the second stage, the information contained in the models is combined with the relevant areas of the shortwalls. Mathematical operations are carried out on the models, e.g. the volume is the product of the thickness recorded in the model and the shortwall surface recorded in the database. Apart from quantitative and qualitative parameters of the shortwall area, additional information is inputted into the appropriate tables of the database. This includes such information as the name of the working level from which the shortwall is to be extracted, the name of the working excavator allocated to the level, etc.

The next step consists in designating the progress of exploitation within defined intervals of time so as to ensure that the quantity and quality of the coal earmarked for extraction is as close as possible to the anticipated levels. This operation is facilitated by the SoftMine suite.

If the designed shortwalls fulfil expectations, i.e. the values obtained are within permissible limits, the information is transferred from the Reserver program to the basic tables of the databases.

If the values obtained are outside the tolerance limits, the design and scheduling operations are repeated until the anticipated effect is achieved. This cycle is repeated until the point, at which the difference between the expected value and the calculated value is accepted by the designer and the mine management. After these operations have been carried out the results are transferred to the database on the basis of the appropriate procedures.

In order to create reports describing the shortwall, report spreadsheets forming part of the SoftMine suite that have been specially written for this purpose are used. The results obtained are presented on scheduling maps, which in addition to topographical information contain the contours of shortwalls together with quantitative and qualitative parameters.

The implementation of the Integrated Information Management System at the 'Turów' Mine, whose core has been the relational database (SQL Server), brought a change in the organization of information flow within the mining

department of the mine. The previous system of personal exchange of analogous documents has been replaced with the exchange of data via the network based on client-server architecture. The system possesses the safety systems based on Windows NT and SQL Server security, as well as CheckPoint type tools. The system has been installed at the mine at the moment the management board became aware that without IT support in the situation where a lot of information comes from various sources the coal mine is threatened with a loss of production continuity. The implementation of the system brought about the ordering of data, the proper assessment of the data quality, higher quality of analyses, and the possibility of alternative presentation of the quantitative and qualitative models of the deposit, as well as the impact on the environment and the mining output. The activities related to production planning and its simulation were previously impossible to be achieved at the level expected by the management board. Currently, it has been noticed—due to the implementation of the savings system—that the costs of the system establishment have been too high. However, there are symptoms indicating that the existence of the system and its further development will allow the mine to optimise the mining activities.

Conclusions

For several years work has been performed aiming at integrating information flows with a view to attaining the result in the form of the Integrated Information Management System, which facilitates the optimization of useful mineral output. This work has been carried out via the co-operation of domestic and foreign centres. The only site in Poland, where these design projects have been implemented to date is the 'Turów' Brown Coal Mine.

In the 'Turów' mine, the work on the implementation of the Integrated Information Management System has reached the stage, at which the design of the exploitation process up to the termination thereof has been drawn up on the basis of a digital deposit model and the storage of the internal overburden has been modelled. According to the authors of the study entitled 'Technologiczne przygotowanie eksplotacji złoża węgla brunatnego 'Turów' [Kaczarewski, T. and Solowczuk, M. 2002] ('The technological preparations for mining the brown coal deposit of the 'Turów' mine') considerable savings have been achieved '... thanks to a reduction of the investment plans that had hitherto been in place, such as the construction of a third ZHOT-11500 dumping conveyer and the conveyor flight planned therefor and also the resignation from the construction of the large T-II/5 intermediate pumping station...'. The cost of one dumping conveyer comes to approximately PLN 70 million and 1 km of conveyor costs approximately PLN 6 million (USD 1 = PLN 4.1). The subsequent steps shall be the works aimed at the integration of the information flow between the mining planning department and the exploitation departments, plus finally with the financial department.

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