R. MIELIMĄKA, P. SIKORA

Silesian University of Technology, Gliwice, Poland

PLANNING OF HARD COAL UNDERGROUND MINING OPERATIONS IN THE ASPECT OF GIS TOOLS

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Purpose. This article will discuss the general problems in planning hard coal underground mining operations. The conditions of Upper Silesian Coal Basin perfectly illustrate the complexity of that process. The exemplary concept modern IT Production Management System will be shown. of. The multitude of data contained in the central database allows to take a full advantage of the capabilities of GIS tools that permit fast spatial visualization of the coal deposit and efficiently manage multiple tasks of planning of the mining operations. **Methodology.** The build-concept of integrated IT Production Management System, which will presented in a very general way, was inspired by results of a detailed inspection of the example of a similar system developed for a mining company in the Upper Silesian Coal Basin in relation to PRINCE2 standards. **Results.** The benefits of this type of modern solution are particularly evident when planning mining operations in complex, multi-plant mining companies. By taking full advantage of the capabilities of GIS tools it is possible to look at the hard coal deposit from a much wider perspective than with a single mining plant, which improves the rational mining economy. **Scientific novelty and practical significance.** Presented concept of the build of integrated IT Production Management System allows quickly create multi-variant hard coal deposit development projects, taking into account all the factors that limit the output of the deposit. The system allows the flow of information between dependent business areas and for data to be stored in one place without duplication. The data collected in a central database exemplifies the full advantage of the capabilities of GIS tools in the complex process of planning of production.

Key words: GIS, hard coal mining, planning mining operations, mining deformations.

Introduction

The process of underground coal extraction in conditions in the Upper Silesia Coal Basin in Poland (USCB) is extremely complex [Kowalski, 2015]. The most important difference between similar regions in the World is the high level of urbanization of the mining areas. Borders of multiple mine industries closely adhere to each other. The rock mass is highly damaged by past mining operations. Thus it's very hard to plan further extraction. Before extraction of a new longwall the entrepreneur must first predict its impact on the surface. The prognosis must be compared with the information about the strength of building objects in the direct operating range. If predicted damages will be smaller than objects strength then the mine industry can start thinking about the extraction of the seam. If some object will be damaged in consequent mining operation, then the mine industry must revenue or repair the object.

Coal is one of the fundamental resources in Polish economy. However, the situation of national coal mines becomes increasingly difficult. Today underground extraction of coal becomes not profitable. Therefore, mine industries are grouping. Potential coal mining areas are changing, there is a need to look for extraordinary mining plans for further extraction. Planning the mining operations needs spatial information about the deposit and objects on the surface. Among multiple extraction projects only a few have a chance to be accepted. Complicated calculations, the variety of spatial data (e.g. set of existing underground cavities, deposit data, faults inside the rock mass, data about past extraction and building objects on the surface) and multiple law aspects force the need of a centralized database and a tool that allows for integrated planning of mining operations. Commonly known GIS tools are very useful here [Poniewiera, 2016]. They are being used, for example, for buildings damage risk assessment, in the process of managing of surface objects as well as for coal deposit management. Many of these difficult issues are inter-linked.

Aim

The main aim of the article is to indicate the practical use of GIS tools when planning production in an underground hard coal mine. For this purpose, it is necessary to properly prepare and centralize the numerous necessary data. The additional goal is to show the complexity and quantity of business processes (in the sense of methodology of PRINCE2 [Bradley, 2002]) that provide data which without GIS tools would be useless.

Underground hard coal mining in the region of Upper Silesia Coal Basin

Upper Silesian Coal Basin is well-known for its heavily concentrated heavy industry and its large urbanization areas. The history of mining goes back to the XIV century [Kowalski, 2015]. Nowadays there is more than 120 [Główny Urząd Statystyczny. “Ochrona środowiska 2013] documented deposits of coal with resources of about 40 million tons of hard coal (about half is actually developed).

Borders of multiple mine industries closely adhere to each other. Many mining companies have to co-exist in close proximity in this environment. Fig. 1 map shows the boundaries of mining areas against the background map of the surface development. This map shows both the huge neighboring urban agglomeration near Katowice (the Upper Silesian Industrial Region – USIR) and the Rybnik (the Rybnik Coal Area – RCA).

Underground hard coal mining in the region of USCB is mostly base on a longwall system [Hamrin, H., 2001]. The empty space in the rock mass after the extraction of coal is eliminated usually by the natural process of rock collapse. Next (almost immediately), the surface is lowered layer by layer inside the rock mass, towards the surface. Such action on the land surface results in the formation of so called subsidence trough which is a kind of linear deformation [Kowalski, 2015]. Subsidence causes changes of slopes, horizontal displacements, extractions, tensions, and land curvatures that are destructive for building objects, landscape, agriculture, and also causes changes in hydrography.

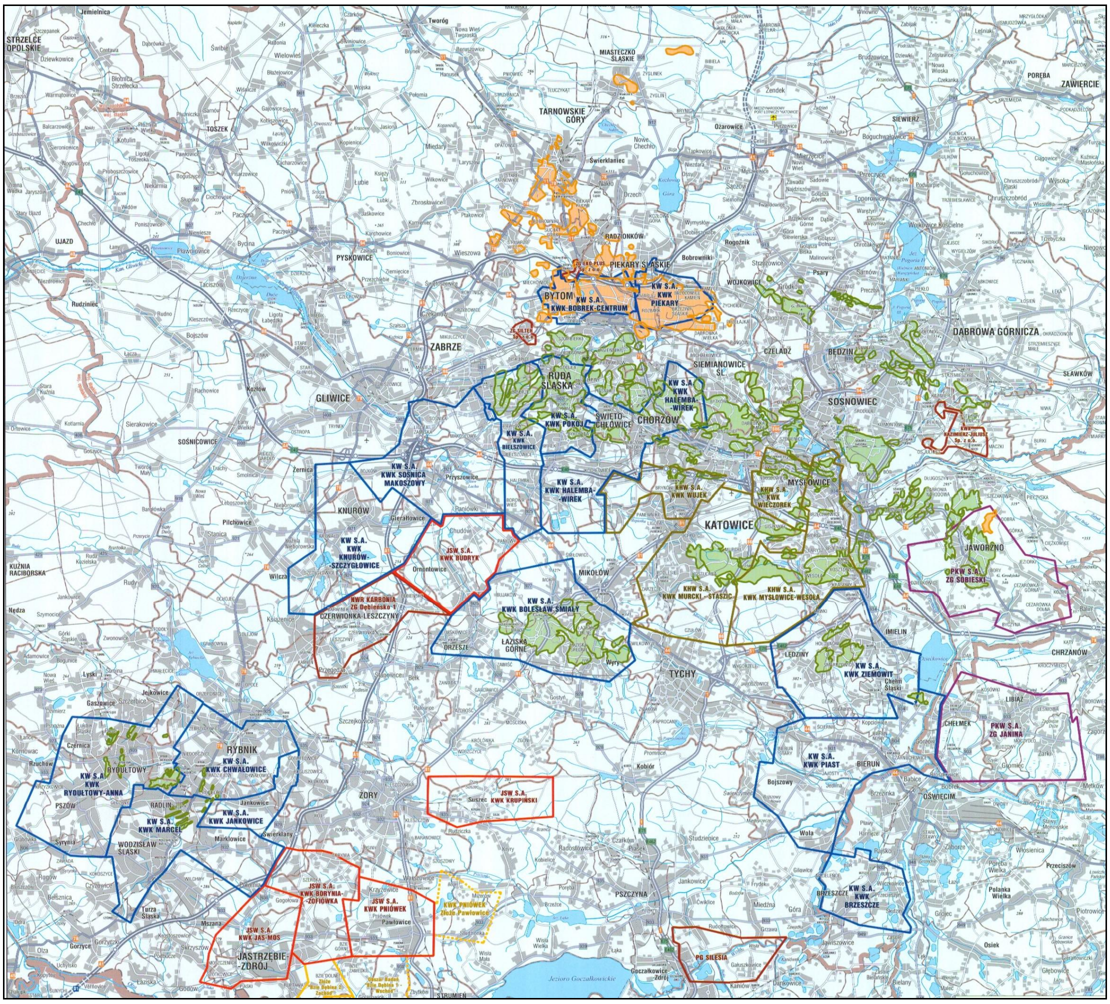

Fig. 1. The map of boundaries of mining areas against the background map of the surface development [Proceedings of the 4th Domestic Conference, 2013]

Every project of longwall extraction must be preceded by risk assessment of mining impact on the surface. The category of mining influences in the direct operational range must be lower or equal to the category of building object's strength on the surface. Mining entrepreneurism has a very limited possibility of reducing the impact of mining on the surface, even if there are any that are closely connected with limitation of extraction, it would cause limited profits.

The situation of national coal mines becomes increasingly difficult. Today underground extraction of coal becomes not profitable whenthe depth of extraction exceeds 1 km. Therefore, mine industries are grouping which results in changing mining areas. Thereis a need for applying extraordinary mining plans for further extraction. Planning the mining operations needs spatial information about the deposit and objects on the surface. Among multiple extraction projects only few have a chance to be accepted. Complicated calculations, the variety of spatial data (e.g. set of existing mine workings, deposit data, faults inside the rock mass, data about past extraction, and building objects on the surface) and multiple law aspects together force the need of a centralized database and a tool that allows for integrated planning of mining operations.

Application architecture of IT Production Management System

Planning mining operations is a complex process. It is not only about the cartographical data and GIS tools [Bielecka, 2006]. The variety of mining tasks that impact the operational project is more complicated. This means that a tool for planning mining operations must integrate all areas of production. The GIS tools will be a part of the integrated system used for collection, processing and sharing of the data required for safe mining and modeling of: mine workings, structure and quality of the deposit, hydrogeological conditions, and the impact of the mining operations to the surface [Jelonek, Poniewiera, Gąsior, 2015; Poniewiera, Sokoła-Szewioła, 2014]. The assessment of the state of the company, its individual business areas, and its needs in terms of capabilities should be systematically structured. The PRINCE2 (Projects in a Controlled Environment) project management methodology seems to be a good choice here [Bradley, 2002].

The concept of modern and complete IT Production Management System should cover the following issues [Bradley, 2002; Tauron Wydobycie, 2015]:

– application architecture,
– data architecture,
– integration architecture,
– architectural code,
– product and hardware specifications of the integration components.

Typical conditions of USCB underground mines can be separated into a few most important areas of architecture application [Bradley, 2002; Jelonek, Poniewiera, Gąsior, 2015; Tauron Wydobycie, 2015]:

– *MAP* – Management, sharing, development and updating of maps of mine workings and surface maps with infrastructure.
– *NMZ* – Defining, managing, updating and sharing a numerical model of a deposit – the universality is required here (the ability to use the selected database (object-relational) through various IT tools / applications).
– *RGH* – Project of mining works and scheduling of preparatory and operational works.
– *PLN* – Forecasting of production quality, planning and integration of the planning process on the extraction side with the planning of the processing and sales.
– *RPT* – Reporting of mining and manufacturing works in conjunction with the SAP ERP system.
– *LOG* – Tasks of production logistics: transport of materials, equipment and people, also transport of coal and rocks.
– *MIU* – Traffic management of machines and equipment, including monitoring of machines and equipment already exploited in mines.
– *ZNT* – Natural hazards management.
– *DFP* – Defining and managing surface deformations resulting from underground mining operations.
– *ZOP* – Management of surface objects.

Each area is grouping a set of important data that are necessary in the process of planning of mining operations. Most of the information can be easily connected with objects on the digital map and then by GIS tools visualized in any way.

The diagram below (Fig. 2) shows the relationship between defined software components. It was developed for a Silesian mine company [12]. Arrows indicate integration flows between business areas. The diagram below does not take into account internal flows (data interchange between individual components within a single business area). In red, external systems are indicated in relation to the projected integrated system which are (not explained in the article as well as interface ranges pointed above arrows.)

In the Fig. 2 can be seen a component was not previously mentioned, its central repository – database (CSD) which is the heart of the system. Proper integration and organization of system's elements with central database is fundamental in order to scope the use of the GIS tools. Planning system like above (Fig. 2) it's important also to develop the range of interfaces. Properly defining the directions of data exchange and interfaces of the defined components and the central database, allows among other things, to use the full resources of the company and eliminate the duplication of data in its various structures.

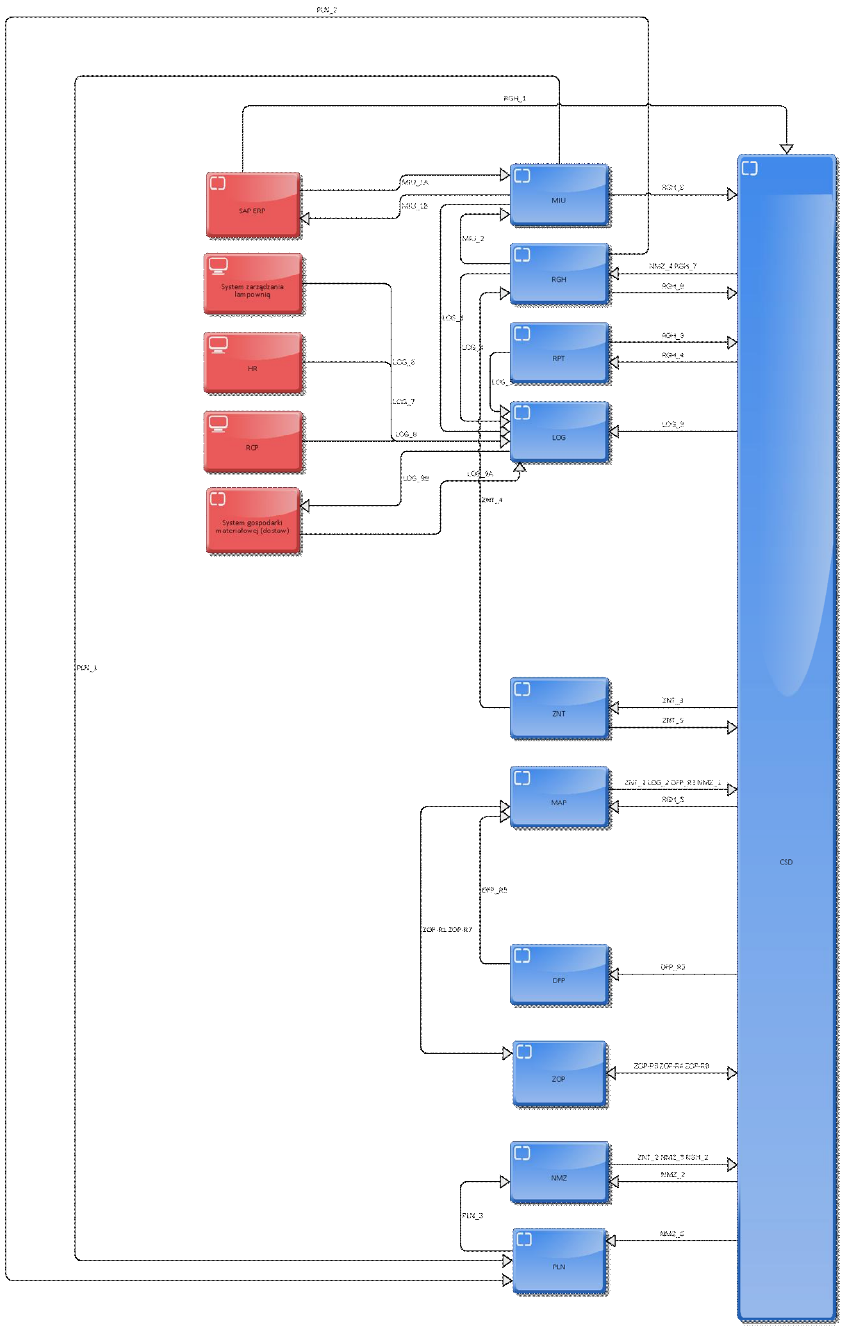

Fig. 2. Exemplary relationship between the defined software components and the central repository CSD [Tauron Wydobycie, 2015]

Central Data Repository

The Central Data Repository (CSD symbol in the Fig. 2) is a unique component of the integrated system design. It is not strictly a component of any business area supported by the system. However, it provides the possibility of mutual communication between functional components and provides functionality common to many areas such as sharing and storing of documents and maps.

One of the most important parts of CSD is its file repository. It provides the ability to centrally store files processed within the projected system and to share them in a controlled way with the individual components and users of those components [Tauron Wydobycie, 2015]. Fig. 3 presents a model of infrastructure for digital map management in case of multi-plants mining companies.

In the Fig. 3 there was shown an example of two enterprises that manage their own map resources (working, accepting and sharing) however the maps are stored in one central database. The advantage of that solution is that global entrepreneur can manage data of all facilities in one place and therefore planning production in a much broader sense.

It must be noted that all services and composite applications delivers Enterprise Service Bus (ESB). This enables individual components to publish data and functionality for other components in the form of services (Fig. 4).

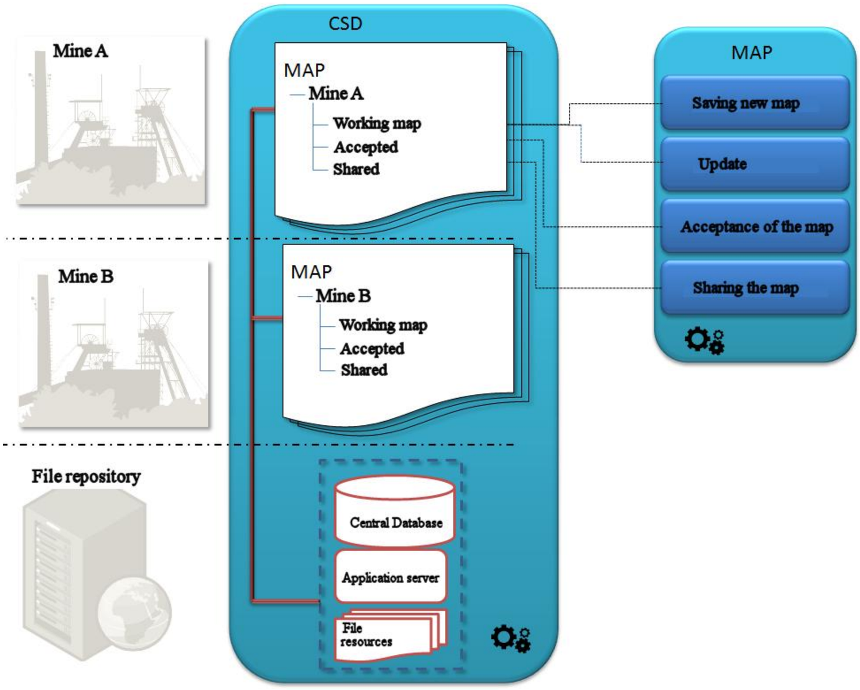

Fig. 3. Digital map management infrastructure CSD [Tauron Wydobycie, 2015]

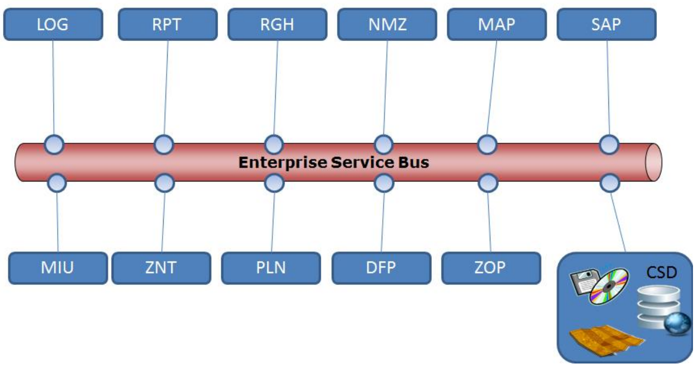

Fig. 4. The concept of Enterprise Service Bus [Tauron Wydobycie, 2015]

Oracle solutions are very often used today [http://www.oracle.com/technetwork/database-options/ spatialandgraph/overview/index.html – Oracle Corporation's official website]. The functional components of the system often include the Oracle Spatial database, which also allows spatial data to be stored and consequently simplify visualization without the need for advanced GIS tools.

Scientific novelty and practical significance

Difficult operating conditions in the form of highly urbanized terrain and long-term and multi-seam mining operations make it increasingly difficult to design new mining applications. Requirements for the protection of mining areas and the constantly increase in mining costs require a special approach to the planning of production. The use of GIS tools in this process, especially in multi-enterprise companies, allows the creation of multivariate projects taking into account numerous constraints. This would not be possible without access to a number of data that is appropriately classified and systematized and stored in a centralized database. The concept of an integrated production system presented in this article is unique on a global scale as well as the conditions under which the mining takes place. A similar solution is already practically applied in one of mining companies in USCB.

The use of GIS tools in conjunction with the integrated production management system requires the use of cartographic resources (both surface and mine workings maps) in numerical form [Poniewiera M., Sokoła-Szewioła]. Tens or even hundreds of years of production give numerous maps that must be transformed into a vector (digital) form. In the case of a large number of classic maps, the only practical solution seems to be so-called vectorization. This process is relatively simple but time consuming. At this stage of work CAD tools should be used. Existing digital maps should be standardized [Poniewiera M., Sikora, 2007]. The raster image must be calibrated first (Fig. 5). The accuracy of the final vector map depends mostly on the accuracy of raster fitting into the coordinate grid.

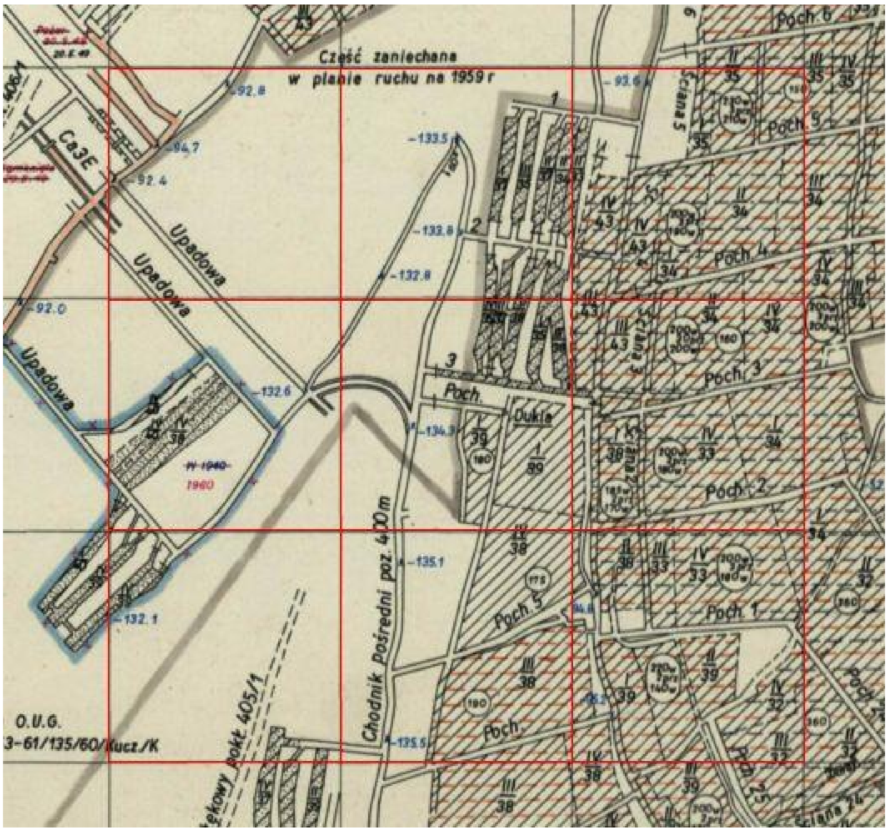

Fig. 5. Calibration process depends on fitting the raster image (map) into the coordinate grid

Next the map should be manually redrawn. This process also cannot be automated. So far only human operator can decide details and properly identify unclear situation on the raster image. The digital map in a form of vector elements is also a data base. There can be assigned descriptive attributes to each object (Fig. 6), e.g. elevation value to the elevation mark on the map, the name, thickness, length, depth to the longwall, and the value of water flow to the water hazard mark. Depending on the system on the map additional objects can be added that are helpful for specialized tasks, e.g. axes of underground walkways in order to help creating digital model of the walkways and digital model of the deposit [Jelonek I., Poniewiera M., Gąsior].

Basing on the vector elements and descriptive attributes digital model of the walkways can be made and also simple visualization from the inside basing on the photographical data (Fig. 7) can be done.

The real capabilities of GIS tools [Bielecka, 2006] trough access to enterprise database resources provide the ability to plan new mine workings taking into account a qualitative deposit model, natural hazards and terrain information. With reference to the global spatial model of underground walkways, itis possible to easily and accurately plan a new walkway e.g. connecting two operational levels (Fig. 8).

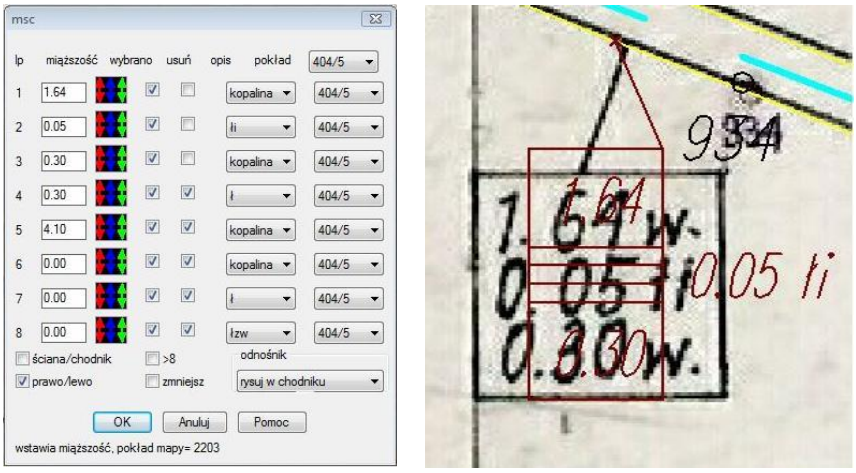

Fig. 6. Assigning descriptive attributes to several elements

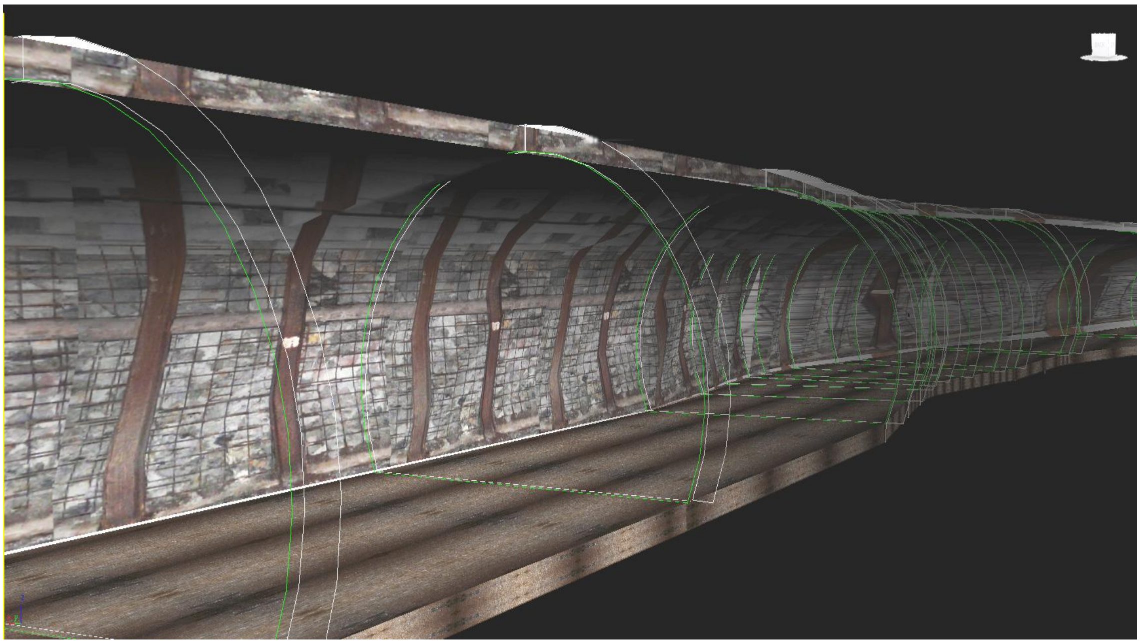

Fig. 7. Creating digital spatial model of underground walkways and simple visualization of walkway equipment

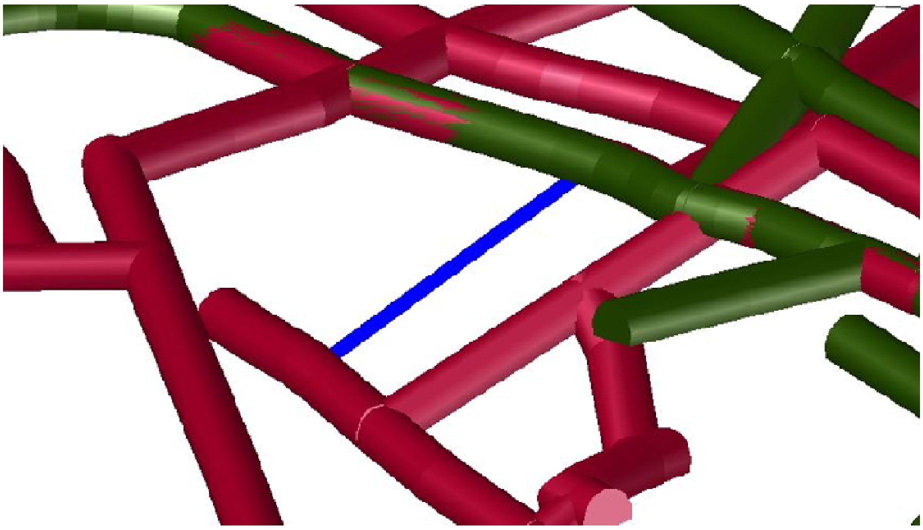

Fig. 8. Project of connecting two operational levels to a new walkway

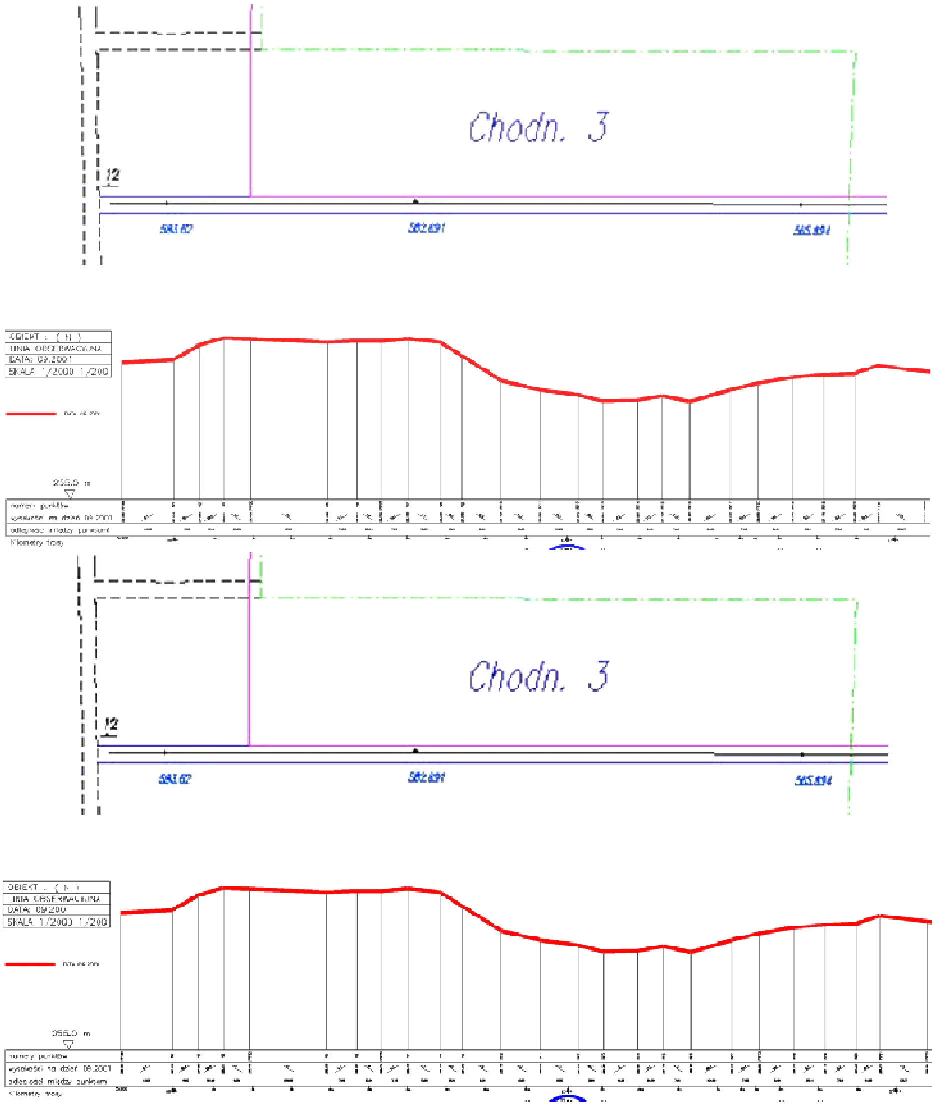

Fig. 9. Longitudinal profile of the planned walkway generated automatically in order of the data about the deposit elevation

Next, based on the digital model of the deposit an automatically longitudinal profile of the walkway (an example was presented in the Fig. 9) can be generated. The information about the inclination is very important e.g. for ore transportation solutions.

Ultimately, thanks to the access of information gathered in a central database, including the data about structure and quality of the deposit, it is much easier and faster to design a new longwall [Jelonek, Poniewiera, Gąsior, 2015]. Planning can take into account many aspects, including scheduling of extraction, arrangement with respect to existing ventilation and transportation walkways, quality of coal and a number of economic indicators. In the Fig. 10 there is presented a map of underground walkways with a project of a new longwall with shading corresponding to the size of coal ash in the deposit.

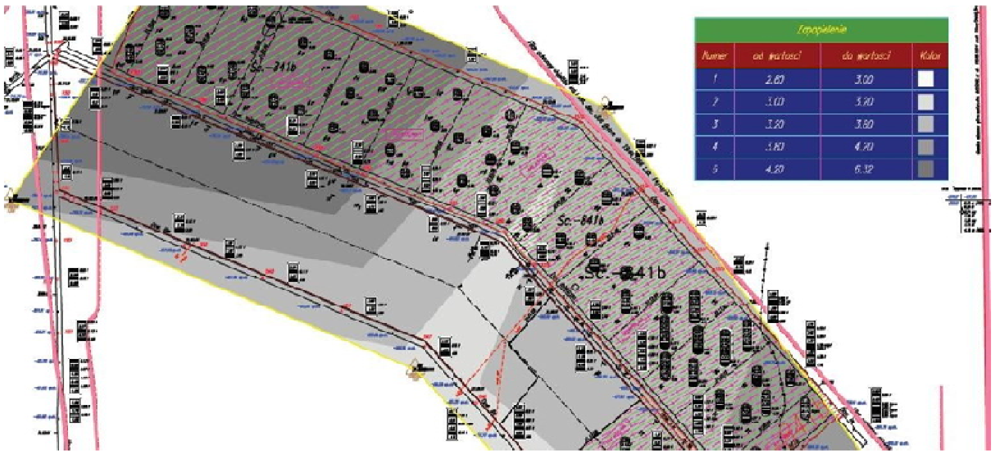

Fig. 10. Map of underground walkways with a project of a new longwall with shading corresponding to the size of coal ash in the deposit

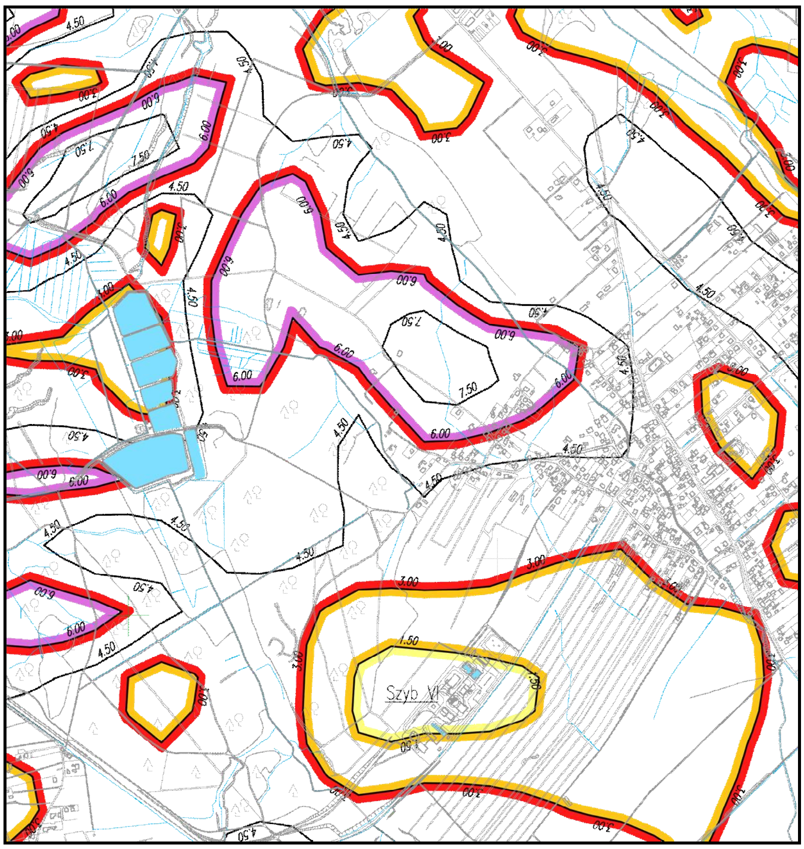

Fig. 11. Surface map with contour lines of predicted values of horizontal deformations E [mm/m]. Colored contour lines indicates the categories of land deformation in 5 level scale (1st– the lowest – is yellow starting from E= 0,3 mm/m;the 2nd is orange and starts from E-1,5 mm/m.; the 3rd is red and starts from E=3,0mm/m; the 4th is purple and starts from E=6,0 mm/m. The highest and 5th is brown and it starts from E=9,0 mm/m)

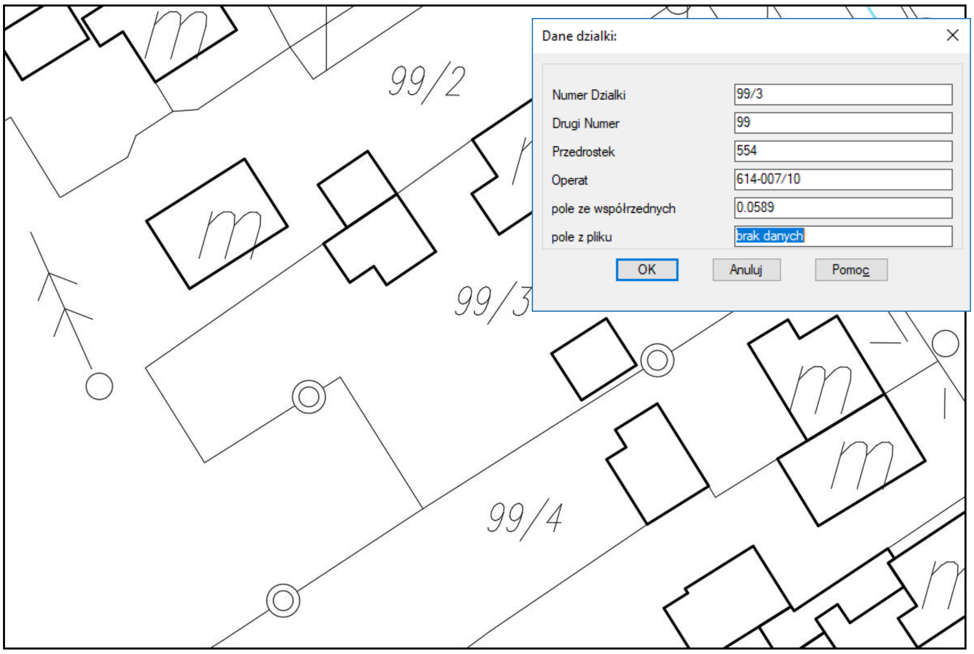

Fig. 12. Example of Identification of the land parcel

The use of additional specialized applications in combination with a complete underground and surface vector map resource allows (by GIS tools) to visualize areas covered by planned mining deformations. An example of such a visualization of the size of horizontal deformations against the surface map was shown in Fig. 11.

Next, a report on exceeding the category of building resistance against a category of terrain is easily to generate in such a system. Also itis easy then (if the information in database are complete) to identify specific land parcel or identify group of land parcels that will be important in order to planmining operations.

Summary

The paper describes the basic problems of underground hard coal mining planning from the point of view of usefulness of GIS tools. However, the GIS tools alone are useless without access to modeled information. That is why this article presents the concept of construction of a IT production management system, which is a rich source of data and in itself contains GIS tools as a tool for planning, interpretation, and visualization of complex data related to numerous mining industry actions.

It should be stressed that the briefly outlined IT system concept is not only theoretical. A similar production management system was implemented in 2014 at Kompania Weglowa S.A [Jelonek., Poniewiera, Gąsior, 2015]. In 2015 Tauron Wydobycie S.A., another Polish mining company, started working on developing such a solution [Tauron Wydobycie, 2015].

This article demonstrates that the use of GIS tools as a part of complex IT production management system that can significantly shorten the time consuming work done in multiple mining departments, ie. geological, mine surveying and mining terrains protection departments. This is especially true in the case of multi-criteria analysis of new longwall projects in order to the damage risk assessment on mining terrains [Hejmanowski, Malinowska, 2010]. The benefits of this type of of modern solution is particularly evident when planning mining operations in complex, multi-plant mining companies. Then it is possible to look at the hard coal deposit from a much wider perspective than with a single mining plant, which improves the rational mining economy.

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Р. Мелімака, П. Сікора

Сілезький технологічний університет у Глівіце, вул. Академічна, 2А, Глівіце 44-100, Польща

ПРОЕКТУВАННЯ ПІДЗЕМНИХ ГІРНИЧИХ РОБІТ НА ВУГІЛЬНИХ ШАХТАХ В АСПЕКТІ ІНСТРУМЕНТІВ ГІС

Обговорено загальні проблеми проектування підземних гірничих робіт на вугільних шахтах. Цю технологію показано на прикладі Верхньо-Силезького вугільного басейну, підкреслено складність виконання цього процесу. Запропоновано концепцію побудованої сучасної системи керування IT-продуктами. Велика кількість даних, що містяться в центральній базі даних, дає змогу повною мірою скористатися можливостями інструментів ГІС, а це допомагає швидко продемонструвати візуалізацію вугільного родовища та ефективно керувати багатьма завданнями планування гірничих робіт. **Методика:** Концепція інтегрованої системи управління виробництвом IT, представлена за допомогою Production Management System в узагальненому вигляді, її розроблено на основі результатів детальної перевірки на прикладі аналогічної системи, розробленої для однієї з гірничодобувних компаній у Верхньосилезському вугільному басейні відносно стандартів PRINCE2. **Результати:** переваги цього сучасного рішення особливо очевидні під час планування гірничих робіт у складних, багатогалузевих гірничодобувних компаніях. За максимального застосування можливостями інструментів ГІС можна дивитися на кам'яновугільний депозит з набагато ширшої перспективи, ніж тільки з погляду одного гірничо-збагачувального комбінату, що покращує раціональне гірничодобувне господарство. **Наукова новизна та практичне значення:** подана за допомогою Production Management System концепція побудови інтегрованої системи управління виробництвом IT дає змогу швидко створювати різноманітні варіанти проектів з розроблення родовищ кам'яного вугілля з урахуванням усіх чинників, що обмежують випуск родовища. Система дає можливість передавати інформацію між залежними галузями економічних процесів, що допомагає зберігати дані в одному місці без дублювання. Результати, зібрані в центральній базі даних, дають можливість повною мірою скористатися інструментами ГІС у складному процесі планування виробництва.

Ключові слова: ГІС, видобуток кам'яного вугілля, проектування гірничих робіт, деформації видобутку.

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