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The characteristics of geographical information systems in terms of their current use

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Abstract

From the beginning of human existence, man collected and analysed information about the space that surrounded him. Nowadays, due to the huge amount of data, it would be impossible without geographic information systems. According to the definition, the main function of GIS (Geographic Information Systems) is to collect, process, integrate, analyse and present data directly collected in the database or obtained through analysis. The basis of each information system's functioning is the collection of relevant data about real-world objects, in terms of their completeness, quality and reliability. Due to the very rapid development of information technology, GIS systems have found a wide application, eg. in spatial planning, real estate management, administration, infrastructure management and many other areas of life. The authors within the article have made a detailed review of the current using of GIS, with particular emphasis on the mining industry. In the latter, particular attention was focused on the use of this type of tools to monitor and analyse the effects of mining activities. At the same time, the authors indicated new possibilities related to the application of geographic information systems in this branch.

Key words: *application of GIS tools, effects of mining activity, geographic information systems, spatial data*

INTRODUCTION

Most of the information that concerns our surroundings is called spatial data relating to the surface of the Earth. From the beginning of his existence, the man collected them and made their analysis, enabling the public to specify the conclusions about their surroundings. Over time, the analysis became increasingly complex and included an increasing amount of data. Nowadays, the amount of data is growing dynamically, which makes it impossible to analyse all information. A very good tool for their collection seemed to be various types of IT systems. However, they did not give the opportunity to present information in a spatial way. It was only geographic information systems that allowed man to gather this information, order and store. Data, constantly updated, enabled conducting complex analyses in a shorter time. What once lasted for months can now be done in a few days.

In each of the systems included in the GIS, several characteristic elements can be distinguished. The most important of them are: data, people, hardware, software and data sharing procedures. It should also fulfil appropriate functions, among which one can mention: data collection, their verification and preliminary elaboration, data management, data processing and analysis as well as visualization.

The rapid development of information technology has allowed GIS systems to be widely used in many areas of life, including mining.

GIS IN HISTORICAL PERSPECTIVE

The beginnings of Geographic Information Systems (GIS) are related to the creation of a computer-generated map. The first program (SYMAP), allowing its creation in such a version, was created in 1964 at Harvard University.

The name of the Geographical Information System comes from the Canada Geographic Information System (CGIS) project implemented in Canada, which allowed to collect information about agriculture, forestry and land using and covered the entire country.

A very important date for the GIS systems was 1969. At that time two companies producing the first GIS programs started their activities, which are still considered as pioneers in the field of Geographic Information Systems. The first of these was M & S Computing, which from 1980 changed its name to Intergraph Corporation. She has developed the first version of the GIS MGE program package. The other was the Institute of Environmental Systems Research, established in California, known under the English name ESRI, which in the 1980s introduced the first version of the ArcInfo program.

The development of Geographic Information Systems would be impossible without a "revolution" in the dawn of computers and information technologies.

In addition to raster data, also vector data began to appear.

The next stage of GIS development was the emergence of databases, which are an integral part of the system. They allowed to combine descriptive data characterizing individual objects with spatial data defining their location. The dissemination of GIS occurred at the time of the appearance of home personal computers, the so-called PCs.

In Poland, the emergence of Geographic Information Systems dates back to the 90s of the last century and to a large extent, it was related to changes that took place in this country (access to scientific and technological thought – mainly from Europe and North America).

Initially, the Geographic Information Systems became interested in academic centers of the largest cities in Poland, ie. Warszawa, Kraków, Gdańsk, Olsztyn, Toruń, Poznań or Wrocław. The first national magazines covering the subject of GIS (Geographical Review, Geographical Journal) and a few local ones [JAŻDŻEWSKA, URBAŃSKI 2013] appeared. Conferences devoted to Spatial Information Systems were organized and the first textbooks on this subject were published.

Along with the systemic transformation in Poland, the development of modern technology has been observed. Breaking the hardware barrier made it possible to create maps in a digital form and has resulted in research work carried out in the most-active academic centers in the field of dissemination of geodetic information systems.

In the Institute of Geodesy and Cartography a Geographic Information System's tool (SINUS – Information System on Environmental Formation) was developed and the first GIS software package was developed in the country, allowing to acquire, collect, process, analyse and share spatial data [BARANOWSKI 2015]. Using it, the first numerical map of land use was made with the detail corresponding to the scale 1: 250,000, which was the basis for the map of Poland. Forests 1: 500,000. Other programs of similar nature are also created, eg. the AVISO program.

Among the topics from publications from that period, dominate those related to the application of GIS to inventory of resources and environmental protection, with the creation of numerical maps as the basic component of spatial information systems and the numerical terrain model.

After 1995, there was a decline in the prices of personal computers, with the simultaneous increase in computing capabilities, RAM random-access memory and graphics card speed, which had an impact on the widespread use of geographic information systems in many industries.

CHARACTERISTICS OF GEOGRAPHIC INFORMATION SYSTEMS – GIS

Geographic Information Systems belong to information systems, distinguished by information about the location of objects and spatial relations between them. In addition, they allow for their cartographic presentation and conducting various types of analyses.

The Geographic Information System does not have one definite definition. There are many of them and, above all, they define GIS as an IT system, consisting of various methods of dealing with spatial data, the implementation of which requires hardware and software, as well as people who can operate it.

According to CLARKE [1990], "GIS is an automated system for collecting, storing, searching, analysing and displaying spatial data".

GAŹDZICKI [1990] defined this system as a system for acquiring, processing, verifying, integrating, manipulating, analysing and presenting data that are spatially referenced to the Earth. It usually includes a spatial database and appropriate software .

According to the definition given at the 5th Scientific and Technical Conference PTIP "GIS is an IT system supporting the collection, analysis and sharing of data about objects uniquely spatially located*"*.

The basic functions of Geographic Information Systems include:
– data collection, verification and preliminary elaboration,
– data management,
– data processing and analysis,
– data visualization.

Acquiring data is usually carried out by direct measurements, methods and techniques of photogrammetry and remote sensing, GNSS technology, as a result of transfer from other systems or by using existing documentation in tabular form or in the form of maps. Descriptive data can be entered into the system interactively or by means of a batch. Acquiring and processing into a coherent form of the data model being created is often a long-term, costly process requiring considerable work. It is estimated that in many projects this phase requires up to 80% of time and costs. At the same time, this is the decisive stage for the quality of final results.

Access for digital files, it is possible thanks to the database management system. It allows you to supplement, search, update and organize data. One of the most important tasks in this field is to protect the system against data damage and access by unauthorized persons.

Transformation, analysis, aggregation and generalization can be distinguished among the processing functions. Some of the processing functions perform only operations on objects without changing them. Another group of processing functions generates (creates) new objects based on existing ones, and yet another can only modify existing objects.

The last group of basic function concerns the output of data in a specific form. This function is aimed at presenting data in an intelligible form to the user and making them available both in the form of paper printouts and in numerical form.

A characteristic feature of Geographic Information Systems is that they consist of five basic elements (Fig. 1).

The organization of spatial data in GIS is based on a layered structure – thematic layers – raster and vector (Fig. 2).

Fig. 1. Components of Geographic Information Systems; source: own study

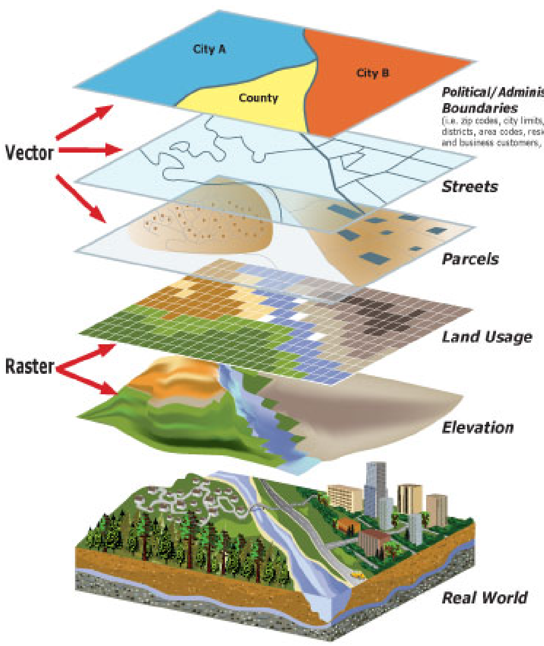

Fig. 2. Exemplary thematic layers in GIS; source: UNC Charlotte [undated]

GIS allows to integrate data from various sources but about the same object or phenomenon. This is possible only when the location is known, hence spatial reference to a specific place on the Earth's surface.

Geographical Information Systems allow to perform various types of spatial analysis, which gives them a universal character and a wide range of applications.

CHARACTERISTICS OF THE GEOGRAPHIC INFORMATION SYSTEMS APPLICATION

As mentioned earlier, GIS allows to combine data from various sources and various types (vector, raster, descriptive data). They also allow to conduct complex spatial analyses, data visualization and simulations of processes and phenomena occurring in our environment. Thanks to such wide possibilities, these systems have been used in many fields, including in forestry and agriculture, in administration, in environmental protection, in crisis management and rescue, supporting the work of many services such as: police, fire brigade, ambulance, transport, banking, pharmacy, insurance, spatial planning and many others.

According to GŁOWACKI [2005], there is currently no field of knowledge related in any way to geography or Earth sciences, which are not related directly or indirectly to GIS.

Geographical Information Systems have found the greatest use in public administration offices. Their main task is to support the decision making of local or state authorities, allowing visualization of various processes. Thanks to them, it is possible to plan certain investments taking into account various parameters, including whether there are utility networks in a given place, whether a given plot has access to a public road, etc. [FELTYNOWSKI 2012].

Performing all kinds of urban works, requires gathering and analysing a huge amount of data, including concerning terrain, its slope, use, insolation, land ownership, threats (erosive or flood), demography, accessibility of public facilities and many others. The Geographic Information Systems help to investigate the relations between these phenomena and to make the right decisions.

As another industry using geographic data systems, network management companies should be mentioned. Thanks to a coherent database, broad analyses supporting network management are possible, including: statistics on the use of individual network elements, estimation of business benefits, failure location, network performance testing, marketing research, network availability determination, process optimization [KĘDZIA, OCIEPA 2015].

These systems are also used with great success in agriculture, taking into account the micro and macro economic approach. GIS software provides unlimited analytical possibilities in this area, aimed at optimizing the production cycle, the registration of agricultural plots, efficient and effective farm management, assessment of conditions for cultivation, yield forecasting or assessment of the correctness of the area's eligibility for subsidies as part of agricultural activities [WINNICKI 2009].

Geographic Information Systems help to optimize forest management activities in connection with the society needs and the economic pressure of the market. This system allows to analyse and visualize complex problems, which helps to make all decisions. It allows, among others, to designate areas for afforestation, create thematic maps, visualize areas at risk on the maps, track and analyse changes in land use (tree felling, changing trees, etc.) [Esri undated].

GIS class tools are also useful during spatial planning, including in the preparation of urban management plans, preparation of development plans, monitoring of changes in the development of space or modelling of change scenarios, eg. modelling of water reservoirs [LUPA, LEŚNIAK 2014].

GIS software is a good tool supporting activities related to environmental management and its protection. As part of the management activities in the Silesian Voivodeship, a generally available database of bio- and geodiversity was developed: BIOGEO-SILESIA, which allows locating objects of interest to the given person and environmental management, and GIS systems together with properly adapted methods allow to create a functional and efficient system for environmental protection activities [PACHURA *et al*. 2016].

The use of GIS has also proved to be very important in crisis management and rescue. The topographic database (TBD) is used for this purpose. Data contained in this database can be used to indicate the location of dangerous objects, planning the distribution of population centers, planning escape routes or commuting to places of disaster. The GIS class tools also enable conducting detailed analyses in the areas of potential threats [DZIEMBA 2015; KOCUR-BERA 2011]. The use of interactive maps in institutions dealing with crisis management allows to improve work efficiency, ex. the police, fire brigade and ambulance services. For example, for the needs of the police, the National Police Information System was created, containing data on persons suspected of committing a crime or wanted people. Also in the State Fire Service, a geographical visualization system was implemented to improve decision-making processes and more effective rescue operations [GAWROŃSKI, TYRAŃSKA-WIZNER 2014].

The Geographic Information System also allows performing various analyses to check the functioning of public transport. It allows, for example, to determine the frequency of buses and trains, which makes it easier for passengers to manage their time [BEGER, POŁOM 2016].

In tourism, these systems allow you to plan a route and assess the condition of tourist routes [EWERTOWSKI, TOMCZYK 2007]. An example of the GIS application in this industry is the geoportal of the Małopolska tourist routes.

The GIS class tools are also used for monitoring the state of cultural heritage, or in the study of historical greenery assumptions. This facilitates the using and management of archival information constituting the source material [WILKANIEC *et al*. 2017]. Geographic Information Systems in this area are aimed at obtaining from various sources of spatial data about monuments, their conversion and integration, data visualization, their sharing and conducting possible analyses, and then monitoring of endangered objects and updating information about them [JAŻDŻEWSKA 2010].

GIS is also widely used in archeology. His main task is to manage newly discovered positions and artefacts. It allows to compile data related to the development of settlement, regarding terrain, altitude, soils, communication routes, hydrological networks, vegetation [BRYK, CHYLA 2014; ZAPŁATA, BOROWSKI 2013].

APPLICATION OF GIS IN MINING

According to the regulations [Rozporządzenie ... 2015; Ustawa ... 2011] it is the entrepreneur's responsibility to ensure safety in mining plant operations, ensuring rational deposit management and environmental protection. An inseparable element of mining operations, starting from exploration and reconnaissance of the deposit, to liquidating a mining plant, is the measurement and geological documentation. Its basic ingredient is the mining map. According to the standard [PN-G-09000-1], mining map is "a cartographic document prepared by authorized persons, presenting the situation and relief, mining excavations situation, geological situation, prepared by geometric projections or a mapping method, intended for mining operations". This document is to ensure proper and safe operation of mining plant operations [PN-G-09000-1]. Technological progress related directly to the creation of this type of documents concerned the maintenance of the map in numerical form and falls on the period after 1995. The result of this are publications and presentations at conferences. An example of this is the Scientific and Technical Conference that took place in October 1996 in Krakow. At the time, the first attempts to create a numerical mining map were carried out using programs operating in the AutoCAD environment, eg. the Draw program, GEOLISP or in the MicroStation environment, e.g. the LC MAPA program.

Programs and IT systems were also created, which main task was to support works in the area of mining area protection.

The Silesian University of Technology has created programs that allow forecasting the impact of mining operations on the surface. The first of them was already developed in 1971 [DRZĘŹLA 1971]. For many years, about 24 programs have been developed, which have been gradually improved and which have gained great popularity in industry, being the basic tool for the work of measuring departments. From 1978, also at the Silesian University of Technology [BIAŁEK 2003] began to develop his programs. The effect of these works (period after 1986) was a series of programs enabling:

– creating, changing and visualizing input data describing exploitation, calculation points (objects), graphic elements constituting the background for contours of operation and contours of calculated deformation indices (programs integrating with the AutoCad);
– calculating the deformation of the mining area;
– determining the parameters of the theory based on the results of measurements;

– determining the size of protective pillars;
– calculating the state of stress and rock strength in order to assess the threat of rock bursts;
– analysis of seismic activity and its forecasting.

In AGH University of Science and Technology at the Department of Mining Surveying and Environmental Engineering, a system called SIOTG (Mining Area Information System) was created. Its main functions are:
– gathering information about the mining area and its development;
– collecting information on mining exploitation carried out and planned and its consequences;
– prediction of deformation of terrain surface and rock mass and determination of the risk level of cubic, linear and special objects;
– predicting hydrological and soil changes;
– graphic presentation of the mining area condition and its threat for different periods and variants of planned exploitation;
– estimating the extent of mining damage and choosing the optimal exploitation options.

As emphasized by the authors of the work [POPIOŁEK *et al.* 1996], "the main function of the Mining Area Information System is to create a database of facilities and terrain, which is the basis for activities to protect against the negative effects of mining operations".

Due to the huge amount of data that is collected and analysed in the surveying and geological departments, in addition to keeping the map in numerical form, it is needed to use Geographic Information Systems in mining plants. First of all, their task is to shorten the time of information searching and to analyse a lot of data from different sources. The base of the system is to be a relational database. Already at that time, it was recognized that programs constituting such a system should enable the collection, introduction, maintenance, updating, processing and modification of data constituting the content of the database.

In 2007, the implementation of an integrated deposit management system was started at Lubelski Węgiel Bogdanka. The basis of the system was a numerical map made in the MicroStation environment, using the SoftMine KWK Map application-ultimately, the basis for the GIS type system.

Also in BOT KWB "Turów" S.A., started to work about the so-called Mining Information System (Górniczy System Informatyczny – GSI). This task began with the implementation in 1998 of a numerical digital 3D map covering the mining area and other area, which together with the relational database of Mining Information System (BD-GSI) was the basic element of GSI [KACZAREWSKI *et al.* 2007].

The next step towards Geographic Information Systems was the creation of a numerical model of the deposit. An example is the Numerical Model of the deposit prepared in Kompania Węglowa S.A., for which an architecture based on a package of engineering applications was used: AutoCad Civil 3D, Oracle Spatial, EDBJ, GEONET and the GEOLISP numerical map service system.

Its task, apart from facilitating the preparation of geological and metrological documentation, was to increase the efficiency and quality of mining planning, because it enabled:
– fast and relatively easy access to collected data;
– fast information exchange by electronic way;
– performing multivariate analyses of a given phenomenon;
– simulation of selected solutions;
– calculation of deposit, loss and exploitation resources;
– planning of excavations providing access to deposits and operational excavations, taking into account all spatial data;
– printing of mining and surface maps at any scale depending on current needs;
– generating any profiles and sections;
– visualization of planned mining works [PONIEWIERA 2010].

The result of this work was the Fusion Middleware SOA Suite software from Oracle, which is a tool used to build a numerical model of the deposit. The system includes the following programs: AutoCad Civil 3D, Oracle Spatial, EDBJ-OPN, GEONET and GEOLISP. This system can be considered a GIS class system.

Over the next years, other GIS rank systems appeared. An example could be the first Land Information System implemented in KGHM Polska Miedź, which covered the entire area of the Company. The system structure included several subsystems such as: cadastral, topography, land deformation, environmental protection, mining damage [KOSYDOR, KRAWCZYK 2009].

An attempt to create a land information system was also made at the Department of Geology and Geophysics in Central Mining Institute. Data were organized in the form of vector and raster sets as well as descriptive information (thematic layers) constituting one issue, eg information on boundaries of mining areas, location of tremors, shallow exploitation, planned exploitation, etc. [KURA 2007].

The three-dimensional model of excavations was also created in the Wieliczka Salt Mine. It was created to improve the mine traffic safety management conditions. Enriched with geological information and after connecting geometric objects with a relational database, it became the basis of the GIS type system [KRAWCZYK *et al.* 2016].

Currently, there is a wide range of GIS software on the market that can support the mining industry (including ArcGIS, QGIS). These systems are also successfully used in underground and open-pit mines. They provide opportunities for, among others, visualization, modeling, database management, resource calculation, mine design or mining project planning. In mining enterprises, GIS are used, inter alia, to identify areas for exploration of resources, assessment of the impact of activities on the environment, planning for reclamation and waste management.

Using the ArcGIS program, ŚWITOŃ [2013] developed a database of graphic and descriptive data for the Thorez mine in the Wałbrzych Coal Basin. The database thus created allowed the author to conduct various spatial analyses, both in 2D and 3D.

The GIS class system is used in the management of various types of rock raw materials, using for this purpose available documentation of the characteristics of deposits, methods of development, use and also ways to manage tchem [BLACHOWSKI *et al*. 2011].

It is possible to use Geographical Information Systems also for monitoring, prediction and assessing the impact of mining tremors on building structures [MIERZEJOWSKA 2018], as well as analysis of the effects of induced seismicity on building structures located on the surface [SOKOŁA-SZEWIOŁA, ŻOGAŁA 2016].

SUMMARY

Until recently, geographical space was described by means of maps. Technological development which took place in the first half of the 20th century allowed for significant acceleration and improvement of this process. The emergence of Geographic Information Systems has brought tools that easily allow to collect, verify, update, process, analyse and present in any form all the data collected in the system. Data ordered in a thematic manner form a single entity, related elements. This is done in a logical way based on the spatial relationships that occur between them. A characteristic feature of GIS is the ability to combine data of various types from different sources (data in vector, raster or descriptive form). Thanks to such wide possibilities, spatial information systems have been used in many areas of life.

The article presents the main areas of GIS utilization, with particular emphasis on the mining industry. Analysis of the available literature allowed the authors to demonstrate a wide spectrum of the use of such systems, ranging from administration, through urban planning, transport, forestry and agriculture, crisis management and rescue, ending with tourism and historical sciences. They analysed in detail the process of adapting these systems to the needs of mining enterprises, in terms of ensuring safety in mining plant operations, rational deposit management and environmental protection.

Taking all this into account, it seems unimaginable nowadays to manage space efficiently without GIS systems. Continuous improvement of the GIS class software may indicate that the application of these systems will be increasing and will affect many different areas of life.

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Charakterystyka systemów informacji geograficznej w aspekcie ich dotychczasowego wykorzystania

STRESZCZENIE

Zgodnie z definicją główną funkcją systemów GIS jest gromadzenie, przetwarzanie, integrowanie, analizowanie oraz prezentowanie danych bezpośrednio zgromadzonych w bazie lub też uzyskanych na drodze przeprowadzonych analiz. Podstawą funkcjonowania każdego systemu informacji jest zgromadzenie odpowiednich danych o obiektach świata rzeczywistego, biorąc pod uwagę ich kompletność, jakość oraz wiarygodność. Ze względu na bardzo szybki rozwój technologii informatycznych systemy GIS znalazły szerokie zastosowanie m.in. w planowaniu przestrzennym, gospodarce nieruchomościami, administracji, w zarządzaniu infrastrukturą i w wielu innych dziedzinach życia. W ramach artykułu dokonano szczegółowego przeglądu dotychczasowego wykorzystania GIS, ze szczególnym uwzględnieniem branży górniczej. Szczególną uwagę skupiono na zastosowaniu tego typu narzędzi do monitorowania i analizowania skutków działalności górniczej. Jednocześnie wskazano nowe możliwości związane z zastosowaniem systemów informacji geograficznej w tej dziedzinie.

Słowa kluczowe: *dane przestrzenne, skutki działalności górniczej, systemy informacji geograficznej, zastosowanie narzędzi GIS*