Development of coal geological information technologies in China

Shanjun Mao[1]

Abstract The history of coalfield geology and mine geology IT applications is over 30 years, which is gaining remarkable achievements. This paper sheds light on the development of geological and surveying spatial management information systems. Specifically, this study proposed the development trend, system structure and function design and sub-systems of the new generation of geological and surveying spatial management information system by benefitting from the recent advancements in computer and spatial information technologies. The sub-systems include the "One Map" online collaborative (2D-GIS) management platform, the geological survey mapping collaborative management system, the integrated service system based on "one map", the three-dimensional dynamic geological model system, the three-dimensional transparent management platform, and water prevention and control information management system. This work is an important foundation to realize the IT information and intelligent management of coal industry. The successful development and application of the new generation of geological and surveying spatial management information system will provide the dynamic data support for the online decision-making of the intelligent coal mining.

1 Current issues

1.1 Overview of China

Coalmine is a traditional industry with a heritage of more than 1000 years. Before the computer technology was applied to the underground coal mine systems, various types of geospatial information, such as coal seam, roof and floor, aquifers, faults, scouring belts, coal seam outcrops, coal seam gas content, and measurement data, were manually processed. Since the early 1980s, with the emergence of computers, especially the microcomputer technology, the former Ministry of Coal Industry of China proposed a strategic decision on modern mine construction.

Following this, the colleges and research institutes invested considerable workforce and resources to carry out IT applications and investigate geological exploration, mine geology, mine survey, hydrogeology, reserve management, and other related fields. Most of the geological prospecting teams, the local mining bureau, and the coal mines set up corresponding computing centers and computer rooms. The microcomputers and their peripherals evolved year by year, and a large number of information management systems were established.

The progress of coal mine geological and surveying spatial information management system is summarized as follows:

(1) Since the early 1980s, a vast number of institutes used the dBASE database management system, as well as BASIC and FORTRAN languages, to carry out database management of coal mine information (including geology, survey, hydrology, reserves, etc.), and utilized AutoCAD like software platforms

✉ Shanjun Mao
sjmao@pku.edu.cn

[1] School of Earth and Space Sciences, Peking University, Beijing 100871, China

to draw simple mine maps. These institutes include China Coal Geology Bureau, China Coal Aerial Survey and Remote Sensing Bureau, Henan Coalfield Geology Bureau, Shanxi Coalfield Geology Bureau, Northeast Coalfield Geology Bureau, China University of Mining and Technology, China University of Geosciences (Wu and Lu 1987), Henan Polytechnic University, Shandong University of Science and Technology, Liaoning University of Engineering and Technology, Taiyuan University of Technology, Anhui University of Science and Technology, Xi'an Branch of Coal Science Institute, Tangshan Branch of Coal Science Institute, and Huainan Mining Group.

(2) From the late 1980s to the mid-1990s, Anhui Coalfield Geology Bureau and Fujian Coalfield Geology Bureau joined the research and development (R&D) efforts on geological IT applications. In addition to FoxBASE, FOXPRO, BASIC, FORTRAN, and C for data management and numerical calculations, they also used AutoCAD for the automatic mapping of mine maps, including geosciences and mining. Furthermore, some researchers used ARC/INFO to conduct special research of mine production, such as mine water inrush prediction.

(3) Starting from the late 1990s, Peking University, Beijing Longruan Technology Co., Ltd., and Xi'an University of Science and Technology worked on the research and development (R&D) of the coalfield geology and mine geological IT applications (Mao 2002; Feng and Wang 2011). The China University of Geosciences also performed considerable R&D work related to three-dimensional (3D) geological modeling of coal seams, which was practically implemented (Li et al. 2011, 2014).

The information provided by the geological prospect department is the basis for mine design, mine construction, and mine processing. The information management is directly related to the process of mine IT construction. Therefore, the departments of coalfield prospecting, management, and production showed much attention to the information management of geological and surveying work, which followed the steps below:

(1) The early and middle stages of information technologies development: limited by the traditional artificial management mode, the database management and mapping systems in their respective fields are developed by the professional and functional departments of coal mine geology, survey, hydrology, and resource management. The data structures of each system are independent and incompatible, which cannot be shared. Its practicality is greatly affected. From the viewpoint of System Theory, the technology and production system of the 3D mine entity is a huge system. The relevant content of each department is the subsystem of a huge system. Each subsystem shares various spatial information, including spatial location and attribute data. The content of all types of thematic graphics of the mine is interconnected. For example, reserve calculation map and topographic geological map include survey data, while mining engineering plan includes the geological data. Therefore, an integrated geological and surveying spatial information management system should be established to make a substantial impact. This technology will evolve the traditional management of geological prospecting and coal mining and provide technical guidance for the modernization of mine management.

In the aspect of graphics processing, most engineers rely on AutoCAD. It is a computer-aided design environment developed by Autodesk in the United States. It is mainly used in mechanical and architectural design. However, the data model and its structure used in AutoCAD are quite different from the geographic information systems. Firstly, it cannot store a large amount of mine attribute data. Secondly, the graphic entities cannot build up a topological relation. This brings great difficulties to the inquiry and processing of the daily information related to the mines.

At this stage, due to the limitations of computer hardware, database, and CAD technologies, the application of geological and surveying information technology has been achieved with unsatisfactory effects.

(2) Coal mine information is a kind of spatial information. Geographic Information System (GIS) is an effective technical means to process spatial information, which is significantly superior to drawing tools, such as AutoCAD, and it is highly recognized by research institutes and companies. Since the late 1990s, domestic research institutes and high-tech enterprises focused on the R&D of geological and surveying spatial management information systems based on GIS technology, which showed remarkable results.

In China, coal prospecting departments, as well as large and medium-scale coal enterprises, have mostly utilized domestic systems based on GIS and network technologies, instead of imported software. These systems are easy to operate and practical, and they meet the needs of the coal mine industry (Yoon and Hyeong 2004; Guillen et al. 2001; He and Zeng 2013). Furthermore, the technologies used in these

systems have reached the level of internationally advanced, some of which (e.g., the automatic processing of faults) have even reached the international leading level. It realizes the network management of geological prospecting and coalmine production departments in geological survey information.

The geological and surveying spatial information management system currently used in China belongs to the category of transaction processing, such as computer mapping, which lacks the functions of decision support and intelligent analysis. Thus, the system can neither adapt to the recent developments in Cloud Computing, Big Data, and the Internet of Things technologies nor meet the needs of large-scale, group and intelligent development of geological exploration and coal mining enterprises.

1.2 Overview of the Foreign countries

For the developed countries, coal is in a relatively minor position in energy production. Although coal is mainly produced in open-pit mines, some of these countries, such as the United States, also have underground mines. However, the technical conditions are as simple as CHN Energy Shendong Coal Group Co., Ltd. Open-pit mines usually have thicker coal seams. After the cover layer is stripped, the coalmine appears as a white 3D geological entity. Here, "white" refers to spatial objections with completely known information, while "gray" refers to spatial objections with partially unknown information. Therefore, the management of spatial information in open-pit mines is much simpler than that of underground mines. In underground coal mines, the data points, such as borehole and underground tunnel geological logging data, reveal the geometry of the coal seam, where other strata are less than the distribution range of the coal. Even if the geophysical prospecting work has been performed in those mining areas or for the mines with better physical conditions, it mainly increases the control accuracy of structures, such as faults. With the tunneling of mine roadways and the mining of working faces, more and more information is acquired about the coal seams. This is the process of the gray 3D geologic entities to become white. In this process, in addition to dynamic modification of the main thematic maps of the mine, the technical and decision-making departments also need to master a large amount of quantitative and qualitative information related to the mining coal seams to meet the production needs.

In open-pit mines, information acquisition relating to coal seams, such as drill hole and overburden stripping, is often realized before mining. In addition to a simple query,

the corresponding information management system is mainly responsible for completing the design of the mining process, as well as the calculation of the amount of coal seam and the stripped earthwork. These tasks can be fulfilled using CAD tools. Therefore, the research made and the software used in mines of foreign countries are mostly related to open-pit mining. The very well-known software systems are Micromine, Crystal, Datamine, EMPPES, and Minex. Through the review of the current literature and the use of some systems, we can see that their design relies on CAD and the related graphics theory.

For China, underground mining is the main method, technical conditions of which are complex. The information management system of a geological survey based on the demand of open-pit mine and CAD technology has not been applied to the domestic geological exploration or well mining departments yet.

2 Development trend and requirements

For both China and foreign countries, the construction of intelligent mines has become the inevitable development trend in the coal industry. In the construction and daily production of mines, high-precision transparent dynamic geological models, tunnel models, and hidden disaster models come to the forefront and determine the success or failure of intelligent mining. Therefore, cutting-edge network and GIS technologies are required to develop a new-generation information management system promoting decision support services for intelligent mining (Wang et al. 2019a, b; Yang et al. 2019; Hou 2017). This system is expected to have the following functions:

(1) One Database: building a database for geology, measurement, reserves, hydrology, and coal quality to provide unified storage for geospatial objects.

(2) One Map: establishing mine geographic information processing standards to realize the distributed collaborative processing of the thematic graphics of geological, measurement, reserves, hydrology, and coal quality.

(3) Dynamic processing and analysis of data: integration of mine geology, hydrogeology, mine surveying, geophysics, gas geology, and other data by using 2D and 3D GIS technologies to realize automatic processing, data mining, and transparent 3D integrated display of the geological and surveying spatial data.

(4) Report generation and processing: automatic classification of the data in the database and the generation of the geological accounts and statements required

for the mine, the company, and the superior authorities.

(5) Geological and survey information integration and office automation: establishing a geological information management platform, which can share various types of geological information to achieve geological office automation.

(6) Establishment of a safe closed-loop system for water hazard tracking and hidden danger control: establishing an integration platform for mine hydrological dynamic monitoring data to realize browsing, query, and evaluation of the current and historical mine data in real-time.

(7) Establishment of a resource/reserve management system: combining *three reserves*, i.e., development coal reserves, preparation coal reserves, and workable reserves, production quantity, and loss-quantity management subsystem to realize the automatic classification and summary report of the raw data.

(8) Establishment of coal quality information management system: realizing the storage and centralized management of coal quality data, such as raw coal and commercial coal, and the statistical analysis of the basic data. Automatic generation of relevant reports and trend curves and performing prediction, forecast, and comprehensive query.

(9) Establishment of digital archives for geological and survey data: collecting classified geological and surveying files, storing the historical archives after digital processing, and realizing the functions of digital archiving, network retrieval, as well as the query.

3 Design and development of a new generation geological and surveying spatial information management system

3.1 System design

The new-generation information management system is applicable to the entire business process of the coal mine prospecting work. It is based on network and spatial information technologies (Mao et al. 2014, 2017, 2018). The architecture of this system is shown in Fig. 1. The "One Map" online collaborative (2D-GIS) management platform constitutes a basis for the whole system, which offers the functions of spatial database management, map editing, file management, and basic drawing. It also provides the mechanism of collaborative processing and information sharing based on the collaborative mapping standard. According to the requirements of production

technology level, as well as the static and dynamic data of the spatial database, the "One Map" platform provides the thematic graphics processing function based on GIS and realizes the distributed collaborative and automatic processing of the mining, plane, section, and hole graphics. The integrated service system based on the "One Map" platform will integrate the graphics, attribute database, and monitoring results, and serve for the remote query and analysis.

3D dynamic geological model system is the comprehensive processing result of the original drilling, geophysical interpretation, plane and section correction, and the measured data of the mine production. This lays the foundation of the automatic generation of the contour map of the coal seam floor and the intelligent mining. The transparent management platform will realize the visualization, attribute query, and thematic analysis of the 3D models, such as surface industry square, stratum, roadway, borehole, fault, collapse column, and ponding area. Figure 1 shows the specific functional requirements of its subsystems.

3.2 The "One Map" online collaborative (2D-GIS) management platform

(1) Establishing data management standards for geological prospecting or mines. According to the types of geology, measurement, prevention, and control of water, standards for layers are established to ensure consistency, sharing, and dynamic update of the data.

(2) Establishing a spatial database engine to realize unified storage and management of thematic graphics, as well as attribute data, such as geological condition, measurement, and prevention and control of water reserves.

(3) Graphic editing function; intuitive, efficient, and flexible data management; query and spatial analysis function.

(4) Flexible customization of professional functions, i.e., geology, measurement, hydrology, and reserves.

(5) Automatic completion of conflict check, consistency update, and historical version management of the map data of the mine.

(6) Using the web online method to maintain, browse, and query map data through terminals, such as computers and mobile devices.
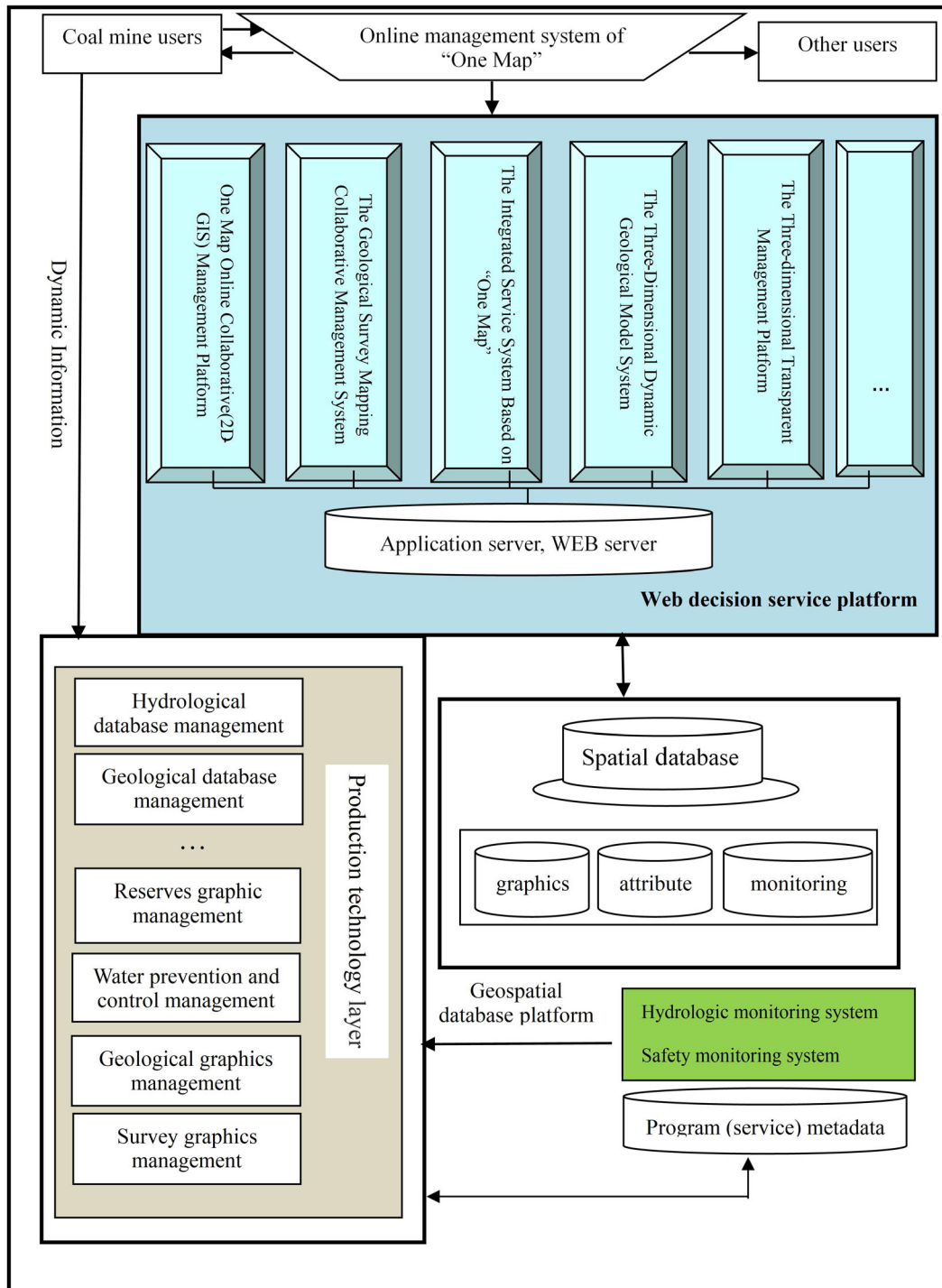
Fig. 1 Architecture of the geological and surveying spatial information management system

3.3 The geological survey mapping collaborative management system

(1) Establishing a database of geology (including gas geology), measurement, and the *three reserves*.

(2) Automatic, semi-automatic, and interactive processing of various thematic graphics, including but not limited to the correction of thematic graphics according to the latest data, and the visualized correspondence between the plane and section.

(3) Realizing numerical calculation functions that meet production and accuracy requirements, such as the calculation of reserve and the survey traverse point,

(4) Realizing automatic and semi-automatic processing of thematic graphics, such as geology, measurement, and reserves.

(5) The multi-professional online collaborative editing based on "One Map", and the synchronous update and sharing of various professional data.

(6) Automatic generation of geological models and coal seam floor contours, besides handling the normal and reverse faults.

(7) Real-timely survey and mapping of the spatial position of the working surface based on laser technology. The update of the mining engineering plan to reflect the latest position of the working surface and provide a relatively accurate spatial information for dynamic alerts against dangerous sources in real-time.

(8) The storage and display of the mining engineering plan should conform to the requirements of GIS topology data structure, and provide topological data for thematic spatial analysis (Su et al. 2019; Shen and Chen 2015).

3.4 The integrated service system based on "One Map"

(1) The "One Map" service release not only query graphics and attribute information but also open graphics or documents and reports of various business systems online.

(2) The online query and analysis of the monitoring data not only query the data of hydrological monitoring, gas monitoring, and gas drainage but also carry out the visual dynamic prediction of relevant parameters.

3.5 The three-dimensional dynamic geological model system

(1) Data sharing with the geological and surveying thematic graphics processing and collaborative information management system.

(2) Constructing dynamic 3D geological models with information on drilling, supplementary exploration, geophysical exploration, geological engineering exposure, gas, and hydrogeology to perform modeling, continuous refinement, and dynamic management of geological results. This is to provide the latest transparent geological models for intelligent mining and excavation.

(3) Establishing a visualized analysis system that can ensure the safe and efficient production of coal resources/reserves, coal seams, structures, coal quality, gas geology, roof and floor, hydrogeology, engineering geology, environmental geology, and other conditions.

(4) Realizing quantitative prediction and comprehensive evaluation of mine geological conditions.

(5) Establishing a technical evaluation system for geological disasters, such as mine gas, water damage, heat damage, and rockburst, based on multi-source geological information, e.g., geological mapping, remote sensing, engineering surveying, drilling, pit exploration, geophysical exploration, geochemical exploration, and exposure. Providing technical support for geological prediction and decision-making combined with geological laws and high-precision dynamic 3D geological models.

3.6 The three-dimensional transparent management platform

(1) With a 3D model database, the users can conveniently store and interactively operate the model to build a 3D virtual scene. This database should have the object-editing function to realize mouse selection, box selection, movement, rotation, scaling, model stretching, and sectioning.

(2) Realizing the configuration functions of various 3D scene attributes, such as layer settings, compass settings, background color settings, display mode settings, and other setting functions.

(3) Realizing layer control, view control, script description, dynamic light and shadow control, 3D inspection, and other functions.

(4) Realizing online publishing, query, and operation of the 3D data.

(5) Realizing data sharing via a 2D-GIS platform with rapid modeling functions for stratas, faults, tunnels, and drillings.

(6) Realizing the integrated display of underground 3D geology and roadway model, collapse column, ponding area, surface 3D industry square model, and surface 3D terrain model.

(7) Realizing the association and dynamic display of the 3D virtual scenes with integrated automation, gas monitoring, personnel positioning, and other online monitoring data.

(8) Realizing the roaming and browsing functions from the surface to underground, as well as the functions of fast 3D scene roaming mode and custom flight route, and fast picture and text information query.

(9) Realizing the authority management of the system, i.e., deleting or modifying the users and increasing their number, besides setting the corresponding menu function according to the authority.

3.7 Water prevention and control information management system

(1) Data sharing with the geological and surveying spatial information management system.

(2) Establishing a special data processing platform to meet the standardization requirements of Special Technical Management System for Prevention and Control of Coal Mine Water (Trial), and realizing the dynamic processing of prevention and control thematic graphics and data.

(3) Realizing the 3D visualization, spatial analysis, and the calculation of mine stratum, structure, roof and floor, and hydrogeological body (aquifer, goaf, etc.) based on the 3D dynamic geological body model, which can simulate the relationships between mining, hydrogeological body, and the water inrush processes.

(4) Establishing a forecast model to achieve integrated management and visualization of the hydrogeological and hydrological monitoring data, as well as water hazard analysis and early warning and emergency rescue systems.

(5) Establishing a virtual collaborative diagnostic system for water hazards based on the multimedia video and the GIS technology.

(6) Establishing a dynamic data processing model to achieve multi-parameter prediction and forecasting of time series data of hazard sources based on production and online monitoring data.

(7) Establishing the level-by-level management and relevant technical measures for the rapid processing of the hazard source information.

3.8 Gas geology information management system

(1) Establishing a gas foundation and management database.

(2) The processing function of the methane geological thematic legend.

(3) The automatic generation of the methane emission curve (content, pressure line) of the mining face, as well as the contour and gas geological map.

(4) Realizing some operations, such as input, modification, deletion, and addition of explanatory data indicating methane pressure measurement points, methane emission levels, methane contents, abnormal gas emissions and inspection points, and outburst danger areas.

(5) Establishing the evaluation index system and the professional model databases.

(6) Predicting the methane distribution and the outburst danger area by combining the gas geological map and the GIS spatial analysis functions.

(7) Dynamic prediction of mine's gas emissions.

(8) Dynamic evaluation of mine's gas resources.

3.9 Digital archives information management system

The digital archives information management system has the following functions:

(1) Processing of the historical and real-time multimedia data of the whole geological and surveying production process.

(2) Sorting, classification, and modification of files, besides the security authority management.

(3) Backtracking the historical (and real-time) data of the whole geological and surveying production process in the mining area.

(4) Two-way query, i.e., locating the map through the attribute table and putting it in the center of the screen automatically, and to query the attribute information through the map.

4 Conclusions and summaries

With 30-years of accumulated knowledge and technology advanced, Chinese coalfield and mine geology IT applications have achieved remarkable outcomes. The domestic software developed for these applications has elevated to a world-leading position. Some example applications are illustrated in Figs. 2 and 3.

Coal will still be the main energy source of China in the long term. Thus, the coalfield geology and the mine geological work must keep pace with the ever-changing needs of both today's and tomorrow's world. Besides, while building *Beautiful China*, *Digital China*, and *Intelligent Coal Mines*, we must make full use of the latest technology for complete management of the geological work. The IT applications developed for the coal industry so far prove that we have enough expertise to build new-generation geological and surveying spatial information management systems to serve the modernization process of the coal industry.
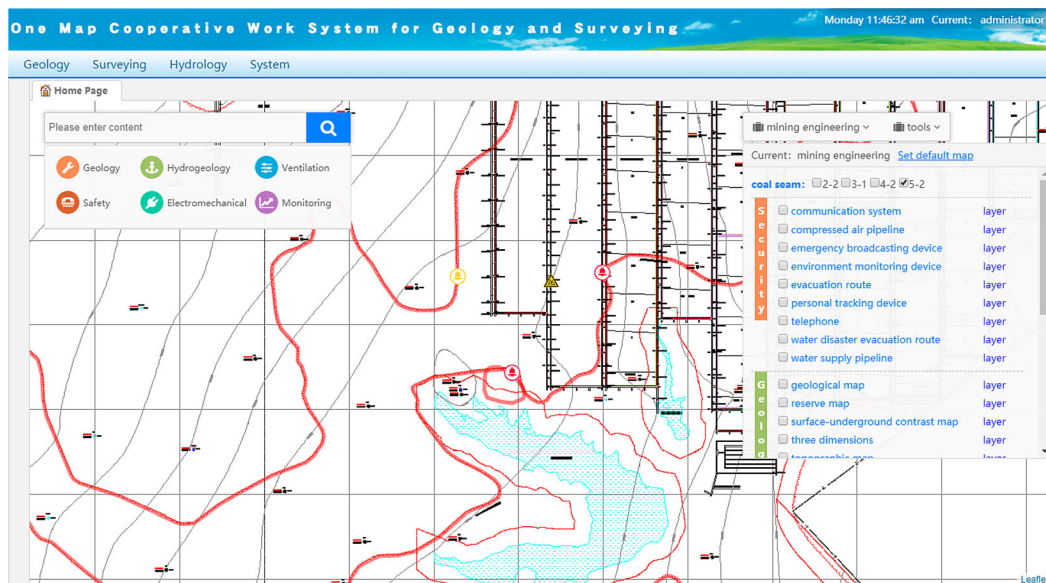
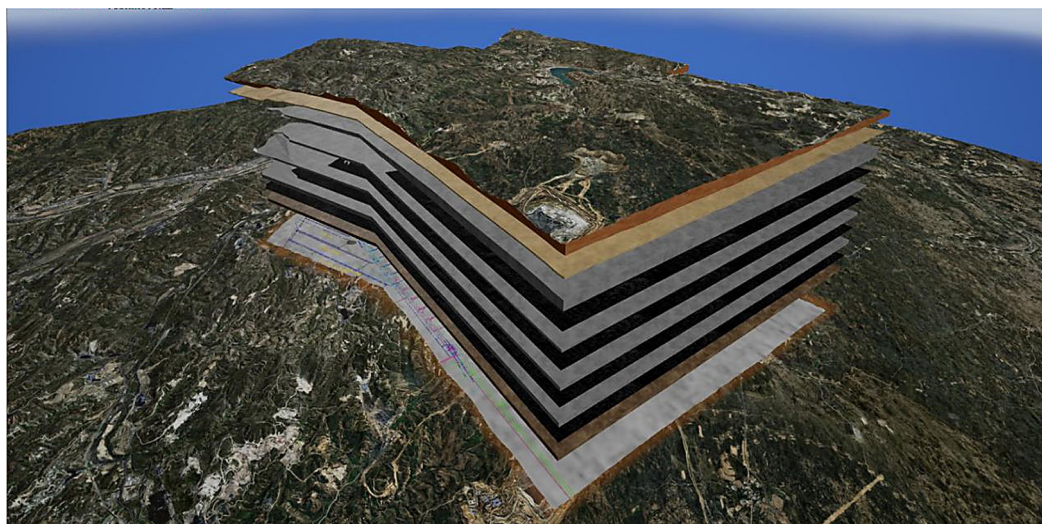**Fig. 2** A snapshot from the "One Map" collaborative management system

Fig. 3 3D geological model of the transparent mine

References

Feng F, Wang T (2011) Coal exploration geological surveying spatial information system based on GIS. Coal Geol China 23(4):64–67

Guillen A, Meunier C, Renaud X, Repusseau P (2001) New internet tools to manage geological and geophysical data. Comput Geosci 27(5):563–575

He Q, Zeng F (2013) Analysis of the application of coalfield geological information resources management based on GIS technology. Appl Mech Mater 380–384:4681–4685

Hou S, Mao S, Li W, Zhang P (2017) Study on key technology of "one map" platform in coal mine. Coal Sci Technol 45(8):32–36+54

Li Z, Wu C, Zhang X et al (2011) Key technologies and development of a 3D coal geological modeling information system. J China Coal Soc 36(7):1117–1123

Li Z, Wu C, Zhang X et al (2014) Dynamic construction and uncertainty assessment for 3D coal-seam models in northern Dongsheng coalfield. Earth Sci J China Univ Geosci 39(10):1498–1506

Mao S (2002) (Gray geographical information system) the theory and technology of correct geological spatial data dynamically. Acta Scicentiarum Naturalum Universitis Pekinesis 4:556–562

Mao S (2014) Strategic thinking and key technology of informatization construction of high-tech coal mine. J China Coal Soc 39(8):1572–1583

Mao S, Li M (2017) Theory and application of gray geographic information system. Sci Technol Datong Coal Min Admin 5:1–5+53

Mao S, Cui J, Linghu J, Sun Z, Chen H (2018) System design and key technology of transparent mine management control platform. J China Coal Soc 12:3539–3548

Su Y, Li M, Zhi N, Mao S (2019) Research on data equalization vector tile construction based on coal mine one-map. Coal Sci Technol 147:1–12

Wang G, Liu F, Meng X, Fan J, Wu Q, Ren H, Pang Y, Xu Y, Zhao G, Zhang D, Cao X, Du Y, Zhang J, Chen H, Ma Y, Zhang K (2019a) Research and practice on intelligent coal mine construction (primary stage). Coal Sci Technol 8:1–36

Wang G, Pang Y, Ren H (2019b) Intelligent coal mining pattern and technological path. J Min Strata Control Eng 2(1):013501-1-15

Wu C, Lu R (1987) Preliminary ideas on establishing point source database system in coalfield exploration area. Bull Geol Sci Technol 02:160–164

Yang K, Miao L, Duan Z, Li M, Cui H, Lv T, Zhang J (2019) Online map service technology and application of coal geological cloud (CGC). Coal Geol China 8:1674–1803

Yoon SC, Hyeong DP (2004) Development of a web-based geographic information system for management of borehole and geological data. Comput Geosci 30(8):887–897