

Article

A Mining Technology Collaboration Platform Theory and Its Product Development and Application to Support China's Digital Mine Construction

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Abstract: At present, data exchange in China's digital mine construction process is still based on paper media or electronic documents. The problems of "information islands," "information versions," "information faults" and "information preservation" are serious. There are many problems associated with across time and space and multidisciplinary collaborations, blocked business processes and unclear job responsibilities. These problems have seriously hindered the construction of China's digital mine, thus restricting the safe, efficient production and sustainable development of China's mining enterprises. Therefore, this paper proposes the concept, connotation, characteristics, architecture and technical requirements of the mining technology collaboration platform and uses it to guide the research and development and implementation of the mining technology collaboration platform of Fujian Makeng Mining Co., Ltd. The results show that the mining technology collaboration platform can solve the information and management problems existing in China's digital mine construction and realize the centralized storage, interoperability and high sharing of all data, the integration of all involved business, business software and its participants, the clarification of responsibilities and its input and output data of each post and standardization and automation of business process. Therefore, it improves the ability to collaborate across time and space and multidisciplinary among participants, departments and professional posts, ensures high-speed flow of business processes and also improves the working efficiency and quality of mining enterprises and significantly reduces the time for business processing and business process flow and reduces production costs.

Keywords: digital mine; mining information modeling; mine's whole life cycle; multidisciplinary collaboration; business process

1. Introduction

In order to achieve the green and sustainable development of the mining industry, safe and efficient mining technology and management methods have always been the goal pursued by mining scholars and practitioners in various countries, and the research and application of mine digitalization, informatization and intelligent theory and technology is one of the concrete manifestations of this goal [1]. Over the past two decades, China has been committed to the research and development of relevant theories, technologies and products of digital mines and has vigorously promoted the construction of digital mines in various mining enterprises, including the construction and deployment of one or several systems such as 3D mining software, production management and control system, communication network system, monitoring and controlling system, equipment control system,

automation system and decision-making system [2–7]. For example, the three-dimensional mining software, communication network system, mine resource and production management system and monitoring and controlling system deployed in Dahongshan Copper Mine [8]; Sandaozhuang open-pit mine has built a dispatching system, an ore distribution system and a monitoring and control system [9]; the equipment control system, process control system and production execution system deployed by Baruen mining company [10] and so forth. The 3D mining software from all over the world is applied in all aspects of mining in China, such as GOCAD, mainly used for geological modeling [11], Surpac for geological modeling boundary optimization and planning [12,13], 3DMine for geological modeling, reserve calculation. This requirement survey and analysis involved six participants, including Fujian Makeng Mining Co. [14] and DIMINE for geological modeling, mining planning, mining design, open-pit ore blending [15,16] and so forth. The above research and application provide advanced technical means for the safe, efficient production and sustainable development of Chinese mining enterprises.

Although China's digital mine construction has achieved certain results, due to the limitations of the objective environmental and technical conditions its application effect on mining enterprises is not very satisfactory and the following problems [2,17–19] must be addressed—(1) In terms of information, the digital mine hardware and software products in the whole life cycle of mines lack uniform data standards and specifications. Each system has its own data format and storage file and the phenomenon of “information islands” is serious. Information transmission is still mostly based on paper media or electronic document-based forms and information is easily lost. The information involved in the whole life cycle of the mine is scattered among the professionals of all parties, departments and posts. Therefore, version issues, information security issues and information fault issues are inevitable and information acquisition is difficult and cannot be shared in real-time; (2) In terms of management, although mining enterprises have carried out digital mine construction, the management structure of mining enterprises is mostly based on the traditional functional organizational structure formed by the division of labor theory, which neglects the flow of business, resulting in the fragmentation of the mine's whole life cycle business process. The cooperation between the parties, departments and posts is poor and conflicts are often caused as they attempt to maintain their respective interests. The duties of each professional position are not clear and repeated work often occurs. There are too many of some business approval links, while some businesses lack the necessary approval links; there is not enough mutual understanding and communication within the same level or between the upper and lower levels in the business, the rework phenomenon is serious and so on. Although the situation of digital mine construction in China is not ideal, the extensive use and promotion of three-dimensional mining software and mine information management systems have laid the foundation and provided the impetus for the collaboration of the mining business. In addition, various problems exist in the application process of products, such as 3D mining software and mine information management systems, which promote its development towards the collaborative direction of integration and exchange based on three-dimensional data.

Therefore, in order to solve the above problems, this paper first summarizes and analyzes the current situation of digital mine construction and the existing problems in China's digital mine construction and then summarizes and analyzes the problems encountered in the digitalization and informatization process of the architecture, engineering and construction (AEC) industry and the solutions adopted. On this basis, the theoretical framework of mining technology collaboration platform (MTCP) is proposed under the guidance of Mining Information Modeling (MIM) and the research and development (R&D) and implementation of mining technology collaboration platform of Fujian Makeng Mining Co., Ltd. is taken as an example. This paper is organized as follows—Section 2 gives the research methods; Section 3 summarizes and analyzes the current status and problems of digital mine construction and the progress and methods of digital and information construction in the AEC industry; Section 4 presents the theoretical framework of the mining technology collaboration

platform; Section 5 takes Fujian Makeng Mining Co., Ltd. (Fujian, China) as an example of R&D and implement mining technology collaboration Platform to verify the theoretical framework of Section 4.

2. Methodology

This research is divided into two stages. The first stage is to adopt a thorough literature review and desktop research methods, (1) to review the history and achievements in digital mine construction at home and abroad as well as the existing problems in China's digital mine construction; and (2) to analyze and summarize the problems encountered, the solutions adopted and the current development trend in the process of digital and information construction in AEC industry. The second stage is to conduct a requirement survey and perform the analysis, perform R&D and implement the mining technology collaboration platform using interview methods and system development and implementation methods. The two-phase results are used to identify and validate the theoretical framework of the mining technology collaboration platform. Therefore, the research results of this paper are based on the following research methods:

- (1) Literature review method and desktop research method—(a) review the progress and achievements of digital mine construction at home and abroad and the research results, construction status and existing problems in the process of China's digital mine construction; (b) analyze and summarize similar problems encountered in the process of digitalization and informatization construction in the AEC industry, put forward the concept of Building Information Modeling (BIM) and developed a series of collaborative platforms to solve the problems encountered under the guidance of the BIM concept; (c) based on the achievements of (a) and (b), the theoretical framework of the mining technology collaboration platform is proposed to solve the problems existing in the current digital mine construction in China.
- (2) Interview method—Based on the theoretical framework of the mining technology collaboration platform proposed in (1), the current situation and existing problems of the digital mine construction of Fujian Makeng Mining Co., Ltd. and the research and development requirements of the mining technology collaboration platform were investigated and analyzed.
- (3) System development and implementation method—Based on the results of (1) and (2), the mining technology collaboration platform of Fujian Makeng Mining Co., Ltd. is developed, designed and implemented, which verifies the accuracy of the theoretical framework of the mining technology collaboration platform from the results of the system's research and development. The theoretical framework can also be optimized and improved through the implementation of the mining technology collaboration platform.

3. Related Research

3.1. Status of Digital Mine Construction

Although the concept of "digital mine" has not been clearly put forward in the construction process of mining enterprises in countries other than China, it still exists in the process of construction and development. It can be traced back to 1952 when D. G. Kring applied the Kriging reserve calculation method to realize the digitalization of resource evaluation [20]; by the 1980s, European and American countries had developed and launched three-dimensional visualization mining software systems, such as the GOCAD, Surpac, Datamine Studio, for exploration data management and analysis, ore deposit and orebody modeling, mine roadway model building, mining design and planning and so forth. [21–24]. Then, by the 1990s, mine information and management systems and mine information system integration technology [25,26] were widely used by mining enterprises in countries other than China. The level of digitalization and informatization of mining enterprises in countries other than China has been comprehensively improved and the effect is remarkable for improving work efficiency and quality and reducing production cost. Therefore, some universities, design and research institutions and mining enterprises in China have successively introduced 3D mining software and

information systems from other countries [27] and put forward the concept of “digital mine” [28], studied the construction framework, construction content and key technologies of digital mine [29–36] and developed a series of digital mine related products, such as 3D mining software system (for example DIMINE, 3DMine), mine information management system, monitoring and controlling system and in large mining groups, such as China Aluminum and China Minmetals, China Minmetals Corporation and China National Gold Group Co., Ltd., has been promoted and applied [14–16], which has greatly improved the level of digitization and informatization of Chinese mining enterprises and has played its due value in reducing production costs and safety accidents and improving work efficiency and quality.

Through the analysis of domestic and international research and development trends, China’s digital mine construction has achieved remarkable results, forming a series of theories, norms, technologies and products of mine digitization and informationization. However, due to the limitations of the practical conditions and technological development, there are still some problems in the construction of the digital mine in China. As mentioned in Section 1, there are problems in information and management. On this basis, it is further summarized and analyzed. The specific contents are as follows:

- (1) The lack of uniform standards and norms for digital mine related products has led to a serious “information island” phenomenon.

The digital mine construction process is based on the existing digitalization and informatization level of the mine and the overall planning and deployment of digital mine related software and hardware products. However, the software and hardware products related to digital mine construction must come from different manufacturers and there is no uniform standard and norm existing between the manufacturers. As a result, interoperability between the products cannot be achieved and a large number of “information islands” are formed [18]. In the situation where there is information that cannot be used, sometimes it is necessary to reacquire the original data or reprocess the data to meet the needs of the products, resulting in the waste of information resources and labor costs. Moreover, due to the existence of a large number of “information islands,” the business processes in the mine’s whole life cycle are not smooth and the business is seriously disconnected and inefficient, which causes the digital mine construction investment and output to be inconsistent, which seriously hinders the digital mine construction process in China.

- (2) Existing products have difficulty supporting the full digital operation of the mine’s whole life cycle business process.

The mine’s whole life cycle business process includes exploration, mining planning and design, production management, measurement and acceptance, mine closure and reclamation and involves mine geology, surveying and mining other business specialties and each professional and business has its own proprietary professional business software and each professional business software has its own proprietary data format. However, limited by practical conditions and technological development, the existing digital mine-related products only support the digitalization of a specific part of the mine’s life cycle business process, a specific business or a specific number of businesses. The fundamental reason is that there is no integrated platform to standardize the data and business processes; therefore, the interoperability, efficient flow and sharing of data in the mine’s whole life cycle business process cannot be guaranteed and the process, standardization and collaborative operation of professional business work, such as geology, surveying and mining in the whole life cycle of the mine cannot be realized, so, ultimately, the full digital operation of the mine’s whole life cycle business process cannot be supported.

- (3) There is a big difference between the traditional operation mode and the management mode of the mine and the informatization requirements.

The development of China’s mining industry has gradually formed a traditional and solidified mode of work and management through historical precipitation. With the increasing trend of economic globalization and world economic integration and the rapid development of

information technology, mining enterprises are facing increasingly fierce market competition. However, most mining enterprises in China still adopt the traditional linear functional organizational structure, which is managed by subdividing the business into various functional departments, separating the complete business process. The operators of each function or production department are usually only responsible for their respective departments, resulting in poor collaboration and coordination between departments; conflicts between departments and between employees in the departments are inevitable and the management efficiency of the “pyramid” organizational structure is low and is unable to adapt to the transient market environment. In the practice of digital mine construction, it is very difficult for mining enterprises to break the traditional solidification mode and try to adapt the digital mine products to the inherent mode or simply transform traditional manual drawing tools into digital operation tools. In essence, there is no change. The fundamental problems of the traditional work mode and management mode still exist, which leads to the system software and hardware construction being independent, serious information island problems, data sharing problems and interoperability difficulties. Therefore, the huge advantages of digital mine construction cannot be reflected. To some extent, it will bring a huge burden to mining enterprises and mine technicians and make it difficult to achieve the digitalization and informatization goals of the mine.

- (4) Lack of practical ideas to guide the research and development of digital mine products and the construction of the digital mine.

In the research and development of digital mine products and the practice of digital mine construction in China, the digital data of the main objects, such as the mining environment, objects, activities and processes have not been effectively organized and expressed, resulting in the data not being able to be shared and the formation of “information islands”; thus, the digitized results of the mine cannot be served for the whole process and mine’s whole life cycle and collaborative operation based on three-dimensional data integration and exchange cannot be realized among participants, departments and professional posts. The fundamental cause of these problems is the lack of practical ideas to guide the research and development of digital mine products and the construction of the digital mine. Therefore, there is an urgent need to put forward a new idea to guide the research and development of future digital mine products and the construction of future digital mines to realize the information sharing and collaborative work of the mine’s whole life cycle.

3.2. Status of Digitalization and Informatization Construction in the AEC Industry

In the process of digitalization and informatization, the AEC industry has experienced the development process from digitalization and informatization of one or more businesses to the digitalization and informatization of the business phase and finally, to the digitalization and informatization of the whole life cycle business, that is, point-line-surface and body [37]. Before the digitalization and informatization of the AEC industry entered the digitalization and information stage of the whole business life cycle, the main problems were as follows [37–41]—(a) there is no professional business software in AEC industry that can cover the whole life cycle of AEC project and it is often only a business software system of a certain stage or a certain professional business in the whole life cycle of the project; (b) because there are no uniform information standards and specifications in the AEC industry, professional software systems from different manufacturers have their own proprietary data formats, which means that the information cannot be integrated and shared and the “information island” phenomenon is a serious problem; (c) since information between various business or business phases cannot be directly exchanged, it often needs to be reprocessed, resulting in information waste and redundancy and an increase in labor costs; (d) although the AEC industry has used 2D or 3D business software to deal with a specific professional business, the exchange of information among participants, departments and professional posts is still mostly based on paper media or electronic documents and information storage issues, version issues and security issues and so on are serious.

From the problems in the digitalization and informatization process of the AEC industry summarized above and compared with the problems in the construction process of digital mine, we can see that the problems in the digitalization and informatization process of the AEC industry and the mining industry are very similar. To solve the above problems and realize the digitization and informatization of the whole life cycle, the AEC industry put forward the idea of Building Information Modeling (BIM) [42–44]. Under the guidance of the BIM idea, the “information island” problem of the AEC industry, as well as information loss, redundancy, duplication, inconsistency and other issues can be well resolved. In recent years, as the BIM idea has been increasingly recognized by researchers, practitioners and government agencies in the global AEC industry [45–47], manufacturers in the AEC industry have also developed a series of collaborative platforms based on BIM idea to effectively organize and manage the information of the whole life cycle of AEC projects and to achieve the collaborative work of all participants, departments and professional posts, as well as the integration and sharing of information, thereby improving the production efficiency and reducing the production costs of the AEC industry [48–50].

Existing BIM-based collaboration platforms in the AEC industry include EXPRESS Data Manager, Share a space, Active Facility, ArchiCAD TeamWork, ProjectWise, BIMserver, G Team, BIMstroms, BIM 360 GLUE, BIMx, BDIP (building data integration platform), Guanglianda BIM5D, EBIM and CBIM [51]. The functions of these BIM collaboration platforms include the following [39,51]—(a) model information management related functions, including model information storage warehousing, model uploading and downloading, model visualization and navigation, model querying, model merging, model comparison, model checking, version management, model information security and document generation; (b) system management related functions, including system security management and document generation, system configuration management and system status viewer; (c) team collaboration and communication related functions, including communication tools such as instant messaging tools and e-mail. Through the above BIM-based collaboration platforms and its functions, the information of the whole life cycle for the AEC industry is integrated to realize the great sharing of information throughout the life cycle and to solve the version issues, security issues, storage issues, exchange and sharing issues of the AEC industry’s life cycle information.

4. A Theoretical Framework of MTCP

Based on the analysis of the current situation and existing problems with China’s digital mine construction and referring to the methods of solving similar problems in the AEC industry, the concept of the Mining Information Modeling (MIM) was put forward. Under the guidance of the MIM concept, the concept of a mining technology collaboration platform was put forward, its connotation and characteristics were analyzed and the architecture and technical requirements of the mining technology collaboration platform were further proposed, which is ultimately used to guide the research and development of products related to the mining technology collaboration platform, see Figure 1.

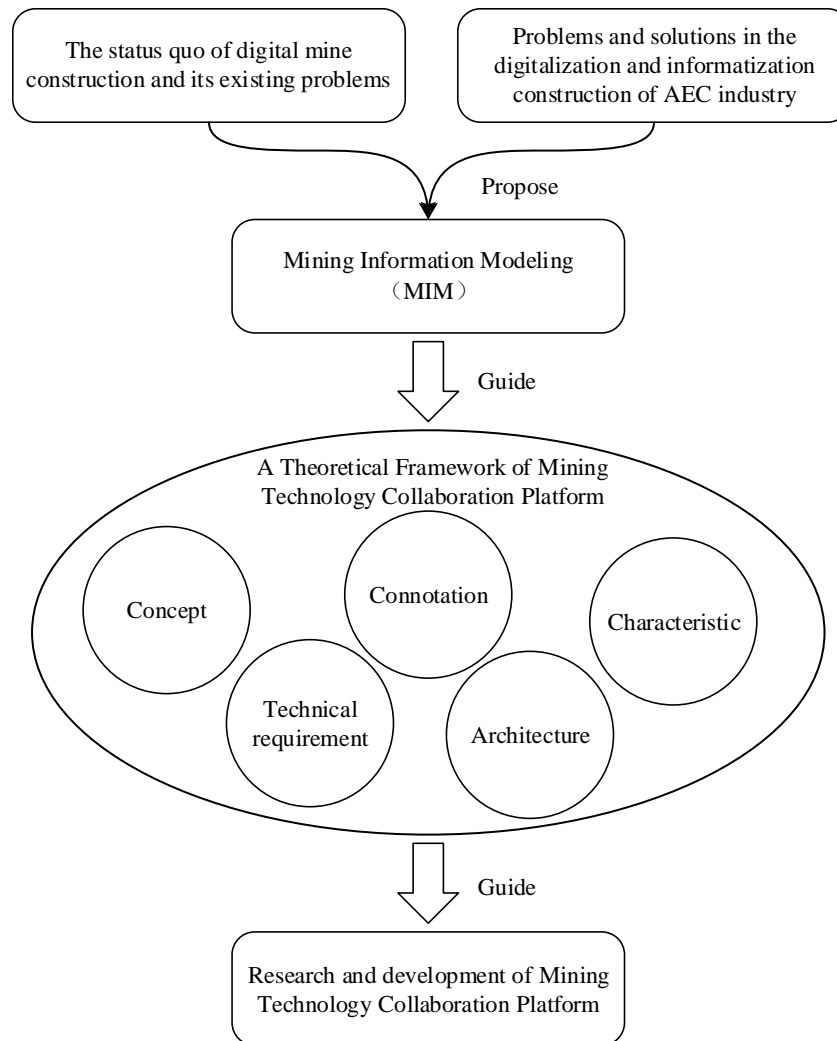


Figure 1. Flow chart of theoretical framework research on the mining technology collaboration platform (MTCP).

4.1. Mining Information Modeling (MIM)

This paper summarizes the digital mine construction achievements at home and abroad and the status quo of digital mine construction in China. Additionally, it analyses and summarizes the four major problems of digital mine construction in China, among which are the lack of practical ideas to guide the research and development of digital mine products and the construction practice of the digital mine, which is the central problem. Therefore, a feasible concept and a series of standards, norms and key technologies formed under this concept are studied to guide the research and development of digital mine products and the construction practice of the digital mine, to fundamentally solve a series of problems in the process of digital mine construction.

It is precisely because of the current strong demand for digital mine construction in China, referring to the concept, method and technology of the BIM and combining with the unique characteristics of the mining industry, we put forward the concept of MIM from the paper “The Construction Target, Task and Method of Digital Mine,” analyzed its connotation, compared and differentiated MIM and BIM and briefly introduced the construction method of the digital mine based on MIM [52].

Mining Information Modeling (MIM) is a digital expression of the mining resources, mining environment and mining engineering objects and digital re-engineering of the mine life cycle’s business processes to realize information interoperability, information sharing and collaboration of various business entities; to solve the problem of information islands in the mining industry; and to

improve the efficiency and quality of the participants. Its contents include the digital model, that is, the geographic information, the geometric and spatial relationships of geological and engineering objects, the quantity and quality of resources and their distribution; the business model, that is, the mine establishes and applies mine data throughout the life period for resource exploration, mining design, infrastructure construction, mining process management and so forth; the method model refers to the business process organization and control process that uses Mining Information Modeling to support the mine's whole life cycle information sharing. Mining Information Modeling (MIM) is a unification of three independent and interrelated parts—digital model, business model and method model.

4.2. Concept and Connotation of MTCP

Under the guidance of the Mining Information Modeling (MIM) concept, the concept, connotation and characteristics of the mining technology collaboration platform are proposed to solve the problems existing in the current digital mine construction process in China and to realize the mine's whole life cycle information integration, interoperability and high sharing and collaboration based on 3D data exchange.

The mining technology collaboration platform (MTCP) is a process, standardized and integrated collaboration platform for the digitalized processing and management of the geology, surveying and mining technology business in the whole life cycle with the support of information technology. Based on the process and standardization management, with the help of the Internet, database technology, cloud computing and other information technologies and driven by business data and business processes, a unified digitized operation environment for mine production technology business processing and management is constructed, which enables all participants, departments and professional posts to work together on the same platform and realizes interoperability, highly sharing and integration of the geology, surveying and mining technology business data in the mine's whole life cycle and improves the team's across time and space multidisciplinary collaboration ability and work efficiency and improves the business processing and management efficiency. The core contents of the mining technology collaboration platform include the following:

- (1) Centralized storage of business data to achieve accurate and effective management of various structured and unstructured data and data relationships and to provide a good security access mechanism.
- (2) Centralized management of the business work to realize centralized, unified and hierarchical management of the environmental parameters such as the design parameters, constraints, technical indicators and technical resources and the effective management and control of the parameters.
- (3) Centralized control of business processes to realize the transformation from "what to do" to "how to do" and "how well to do it" to achieve effective tracking, control and assessment of the business processes.

Through the centralized storage of business data, centralized management of business work and centralized control of the business process, the operators of all participants, departments and professional positions collaborate efficiently on the same platform across time and space to complete the business operations of the mine's whole life cycle, such as exploration, infrastructure, planning and design, production management, survey and acceptance, mine closure and reclamation, to achieve interoperability, efficient flow and highly shared business data.

4.3. Characteristics of MTCP

The mining technology collaboration platform integrates all the businesses of the mine's whole life cycle and the roles of all participants, departments and professional positions involved in all businesses and integrates all the information of the mine's whole life cycle. The four-dimensional relationship between business, role, information and amount of information on the mining technology collaboration platform is shown in Figure 2. In the mine whole life cycle, all business flows with the

business process; during this process, the roles of all participants, departments and professional posts, including professional technicians and engineers, department leaders, supervisors and chief engineers, are required to carry out the corresponding business processing, including the processing of the business technology work and business management work. In the process of business processing, that is, the intersection of the business and the role in Figure 2 (the red point in the figure highlights some intersections) and the corresponding acquisition and generation of information, such as environmental information, resource information, engineering information and activity information. The acquired information is derived from the digital model and feeds back the information generated during the business processing to the digital model. As business processes continue to flow, information with multiple sources, heterogeneity and dynamics is continuously generated, modified and updated and the amount of information is growing geometrically. According to the relationship between the business, role, information and amount of information on the mining technology collaboration platform, the intrinsic characteristics of the mining technology collaboration platform are analyzed, which has the following characteristics:

- (1) Integration—The integration of the mining technology collaboration platform mainly includes the integration of all business in the whole life cycle of the mine, the integration of all business technology work and management work in the whole life cycle of the mine, the integration of all participants, all departments and all professional posts involved in the whole life cycle of the mine, the integration of digital mine related products in the whole life cycle of the mine and the integration of business data in the whole life cycle of the mine.
- (2) Process—The process of the mining technology collaboration platform is to use the idea of process management to efficiently flow all the business in the whole life cycle of the mine to break the barrier between the participants, between departments and between professional posts. In addition, the specific business workflow, that is, the specific business work process is carried out in a way so that the business work process is simplified and efficient.
- (3) Standardization—The standardization characteristics of the mining technology collaboration platform refer to the standardization of business data and business processes. The purpose of the standardization of business data is to realize the sharing of data between all the businesses and the software and hardware of each business in the whole mine life cycle. The standardization of the business process standardizes the business process in the whole life cycle of the mine as well as the business workflow.
- (4) Security—The security of the mining technology collaboration platform includes the control of login rights, access rights of functional modules and access rights of business data of the mining technology collaboration platform.
- (5) Completeness—The completeness of the mining technology collaboration platform includes all business, business processes and data generated by all businesses in the whole life cycle of the mine, such as geological exploration, infrastructure, production exploration, planning and design, production management, survey and acceptance, mine closures and reclamation and so forth. All business data of the mine's whole life cycle include geological exploration data and production exploration data, such as borehole data, pit exploration data, trenching data and geological logging maps; design data, such as mine development design data, cutting design data and mining design data and so forth; planning data for long-term mining planning data, medium- and long-term mining planning data and short-term planning data; production management data generated by the mining processes and related processes, such as ore deposit development, mining accuracy, cutting and mining; and survey and acceptance data of engineering and ore quantity, such as mine development, cutting and mining and so forth.
- (6) Shareability—In the process of mine's whole life cycle business processing, all participants, departments and professional posts can realize real-time sharing of mine business data through the mining technology collaboration platform.

- (7) Traceability—The mining technology collaboration platform can query and track business processes and business data according to business processes, participants, departments, professional posts and operators in the whole life cycle business process of mines to realize the traceability of business processes and business data.

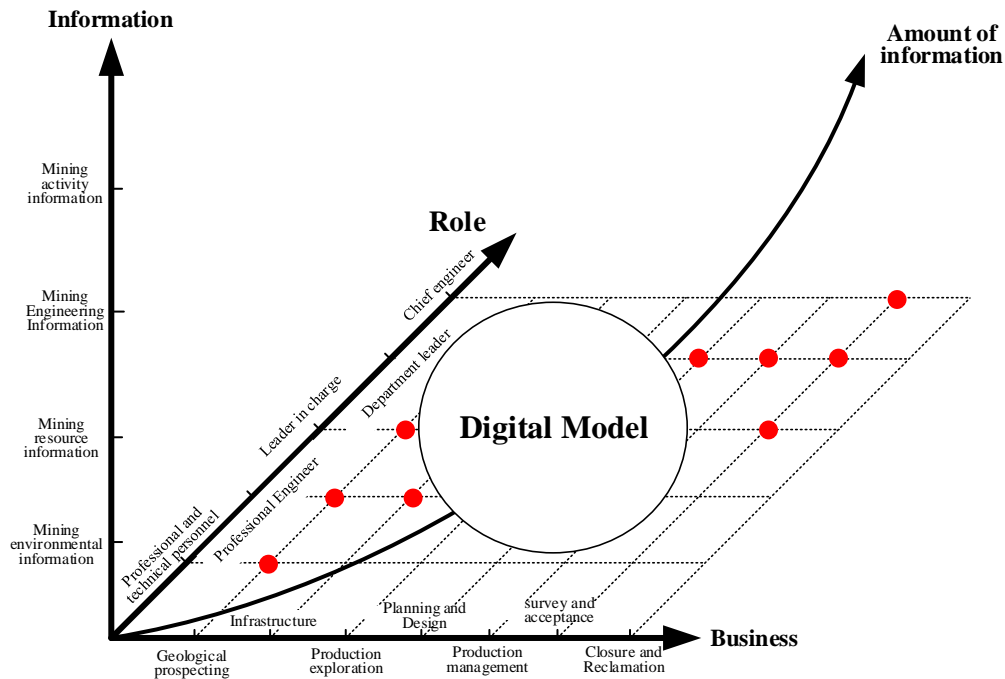


Figure 2. Four-dimensional diagram of MTCP.

4.4. Architecture of MTCP

As shown in Figure 3, the architecture of the mining technology collaboration platform is composed of a data layer, data exchange layer, collaboration platform layer, business software layer and business layer. It is based on data standardization and business process standardization, where information technology, such as the Internet, a database, cloud computing and so forth, is used as a means to form a highly integrated and shared collaboration platform for the centralized storage of business data, the centralized management of business work and the centralized control of business processes. The data layer mainly stores the standardized data of the mining environment, resources, engineering and activities in the whole life cycle of the mine; the data exchange layer mainly converts the source data format from different manufacturers' products into the standard data format to store in the data layer and can convert the standard data format of the data layer into the demand data format of different manufacturers' products and realize the data format requirements of different manufacturers' products; the collaborative platform layer realizes the high-speed flow of the business in the whole life cycle of the mine through the business process and connects the business software of the business software layer through the standard interface of the tool software on the collaborative platform to process the business of the business layer and the data required by each business processing and management process comes from the data layer and is converted into the data format required by the business software through the data conversion layer and the data generated by the business processing and management process is converted into a standard data format through the data conversion layer and is stored in the data layer.

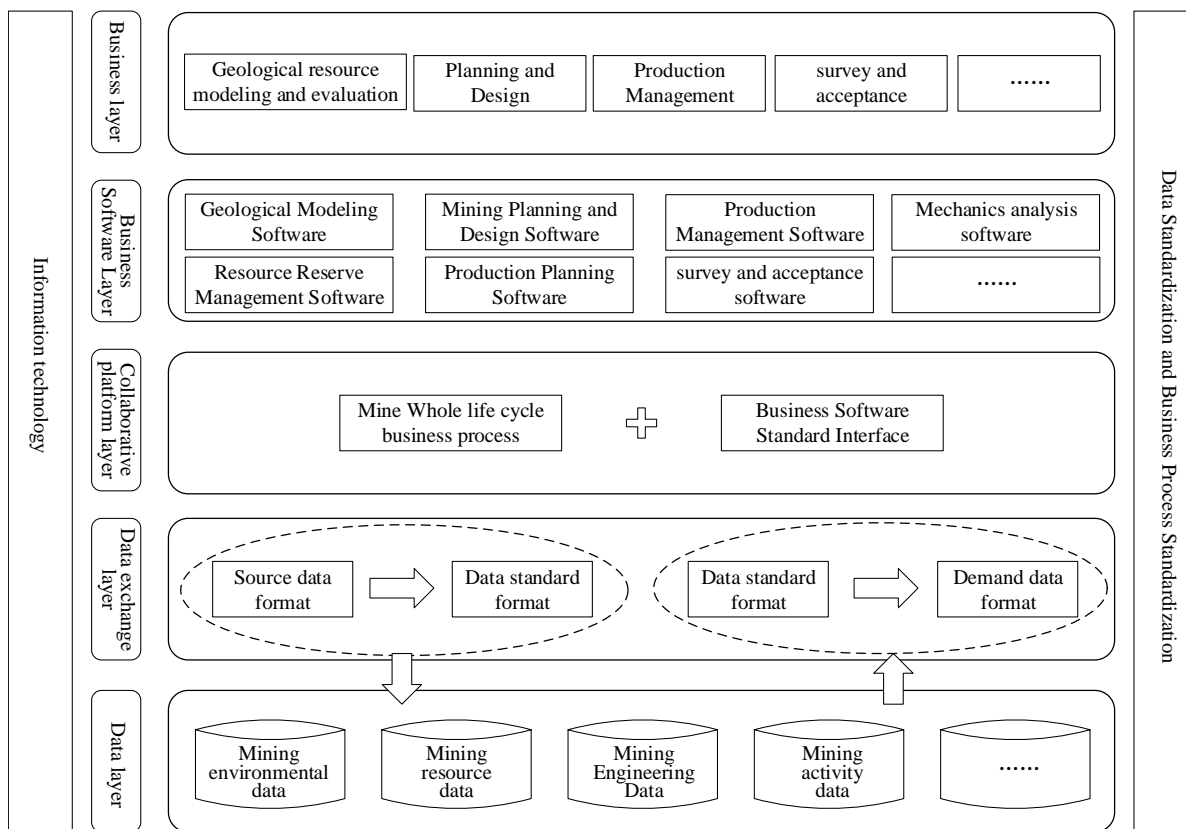


Figure 3. The architecture of MTCP.

4.5. Technical Requirements of MTCP

To further analyze the mining technology collaboration platform, referring to the collaboration platform products developed by the AEC industry based on BIM and on the basis of the concept, connotation, characteristics and architecture of the mining technology collaboration platform, five technical requirements are put forward, including business process management-related requirements, business software system related requirements, model data management-related requirements, mining technology collaborative platform management-related requirements and teamwork communication-related requirements. The specific contents of these five aspects are as follows:

(1) Business process management-related requirements

- Hierarchical management of business processes—according to the different granularities of business divisions, the business has the characteristics of a hierarchy and the corresponding business processes also have the corresponding hierarchy. According to the profession, the first layer can be generally divided into geology, surveying and mining and the second layer can be refined on the basis of the first layer. For example, geology can also be divided into prospecting design, geological logging, geological interpretation, geological modeling, reserve estimation and so on, until it is divided into the appropriate levels.
- Business process definition—although the mine life cycle business phase is the same as the profession involved, with the refinement of the business, different mining enterprises have different business processes with different concerns and needs. Therefore, it should be able to flexibly define the business process according to the business concerns and needs of different mining enterprises and avoid the need for re-coding and developing for different business process definitions.

- Business process visualization—it can visualize the business process definition and simplify the complexity of the business process definition. Additionally, it can visually display the status of the business process flow, clearly show the current process node, each process node and the start and completion time of the whole business process, as well as which process nodes have been rejected and the number of rejections and so on.
- Status management of business processes—the business process status is fully managed, including defining the business processes, running the business processes, archived business processes and abnormal business processes, on the mining technology collaboration platform.
- Management of historical business processes—as business processes continue to be created, launched, streamed and archived, a large number of historical business processes will be accumulated. These historical business processes contain a large amount of valuable information. They can be queried and analyzed by the business, business process, business personnel and initiation and archiving time. The existing problems can be found and the business processes and business work can be optimized and improved to improve the flow speed of the business processes and the quality and efficiency of the work.

(2) Business software system related requirements

- Compatible with the mining technology collaboration platform management side—since the business software systems required for all business processing in the mine's whole life cycle are integrated on the management side of the mining technology collaboration platform, in the business process flow, the necessary information, such as the business process information, user information and authority information on the management side of the mining technology collaboration platform, will be transmitted to each business software system as the business software system is activated to ensure that the relevant information of the mining technology collaboration platform management side is consistent with the relevant information of the business software system to achieve compatibility between the two.
- Upload/download model data—the upload/download mode of model data includes launching the corresponding business software system to upload/download model data during the business process flow and setting up necessary data organization management information to upload/download model data by login to the business software system separately. The downloading of model data should support selective downloading of model data for each historical version.
- Access control—the access control of the business software system includes the login access control, function access control and data access control. The business software system requires a username and password to log in and gain access and can access the corresponding function according to its permission and upload and download the model data under the corresponding authority.
- Data standardization management—to ensure the efficient flow and sharing of business data among participants, departments, professional posts and business software systems, it is necessary to standardize the management of all business data involved in the mine's whole life cycle.
- Business workflow of business software system—to standardize the process of the business software system to handle the entire business work, the entire business process is streamlined and standardized to make the whole business process clear, simple and efficient.
- Two-dimensional drawing and document generation—the business software system can download the model data from the model data storage warehouse and generate various two-dimensional drawings and documents, such as a roadway logging map, geological plan and section map, development design drawings, mining and cutting design drawings, ventilation network solution reports and so forth according to the mine's business needs.

(3) Model data management-related requirements

- Model data storage warehouse—the mining technology collaboration platform is used to store the model data of the mine's whole life cycle, including geological data, resource data, engineering data, activity data. It needs a storage warehouse to organize and manage all the business data effectively for centralized storage.
- Model data objects at different levels—the business data of mine's whole life cycle is stored in the data warehouse at different levels to meet different levels of business needs. For example, the orebody model can be divided into four levels, that is, mine, mining area, level and stope. to meet different levels of reserve calculation, planning and design.
- Unique identification of model data in the data warehouse—to prevent duplicate business data stored in the data warehouse, a unique ID is used to identify the model data object.
- Model data version management—record, track, maintain and control the evolution of all data in the whole life cycle of the mine to avoid loss and confusion regarding the model data.
- Locking of model data—when the model data is being used, it needs to be locked and protected to avoid conflicts between different users.
- Model data security management—the security of model data is the basis for the smooth flow of business processes and business operations. Therefore, it is necessary to ensure the security of the model data in the data warehouse by setting various security mechanisms, including user authentication, access control, data encryption and data backup.

(4) MTCP management-related requirements

- Organizational structure, role and user information management—the purpose is mainly to manage the organizational structure, role information and user information of all participants and ensure that all the participants, departments and professional posts involved in the mine's whole life cycle work and communicate on the mining technology collaboration platform.
- System status viewer—view the users who are logging in to access the system; view which model data is being used, added, modified and deleted by which users; view the status and quantity of the business processes, including the defined business processes, initiated business processes, running business processes, archived business processes and so forth in the system; view the operational status of the integrated business software in the system; view the system's error information and warning information and so on.
- Data dictionary—the definition and detailed description of the data used in the system is the basis for system development, maintenance and use of data.
- System exception handling—the mining technology collaboration platform is based on the business processes and when the flow is smooth, the business will flow efficiently. However, when a process node in a business process cannot flow smoothly, it will cause the subsequent business to not be able to continue, resulting in delays in subsequent business. Therefore, the mining technology collaboration platform must be able to handle such anomalies quickly.
- System Configuration Manager—to ensure the safety of the mining technology collaboration platform, it is necessary to configure and manage the user's access to the mining technology collaboration platform management side, the data warehouse and the business software system and to configure and manage the functional modules of the mining technology collaboration platform management side and business software system according to the business type and the nature of business posts.

(5) Teamwork communication-related requirements

- Group collaboration communication tool—the mining technology collaboration platform is an integrated and collaborative platform for all business work in the mine’s whole life cycle. In the process of all business processing and management, between business technical personnel, business technicians and management personnel, they inevitably need to communicate with each other in terms of business and management issues. Therefore, the mining technology collaboration platform needs to integrate communication software (such as instant messaging tools, e-mail) with business and to consult, advise, answer and review questions through instant messaging, voice, video and e-mail in the business process. Therefore, the mining technology collaboration platform needs to integrate communication software (such as instant messaging tools, email) with the business in the business processing and management process through instant messaging, voice, video, email and other ways to consult the problem and provide suggestions, answers and reviews. In addition, the mining technology collaboration platform can provide knowledge sharing and communication modules, including a knowledge base, knowledge encyclopedia, knowledge circle and knowledge quiz, for the participants to share and exchange knowledge anytime and anywhere in the process of business processing and management.

5. Case Study

To verify the concept, connotation, characteristics, architecture and technical requirements of the mining technology collaboration platform proposed in Section 4, it is used to guide the development and implementation of the mining technology collaboration platform for the construction of digital mines at Fujian Makeng Mining Co., Ltd.

The Makeng Iron Mine of Fujian Makeng Mining Co., Ltd. (hereinafter referred to as “Fujian Makeng Iron Mine”) is located in Longyan City, Fujian Province, China. It is one of the famous extra-large magnet deposits in China. The proven geological reserves of iron ore are 434 million tons, with an average iron grade of 37.99% and the total metal content of symbiotic and associated molybdenum resources is more than 80,000 tons [53]. It has a scale of 5 million tons of iron ore annually. At present, the construction of a digital mine of Fujian Makeng Iron Mine has achieved certain results, including the construction of the underground monitoring and controlling system, the construction of the underground personnel positioning system, the construction of the underground communication system, the construction of the underground emergency avoidance system, the construction of the underground forced air self-rescue system and the construction of the underground water supply rescue system, enterprise comprehensive management information construction, KJ293 (A) railway locomotive transportation monitoring system construction, fan remote control system construction and tailings reservoir online monitoring system construction. However, the mining design is still based on two-dimensional computer-aided design (CAD) software, the mining planning is compiled by EXCEL and the ventilation management depends on the technical and experience level of the ventilation technician. The duties of each business are not clear; the phenomenon of overlapping and duplication of each business is a serious problem; lack of necessary communication and communication between participants is not smooth and the phenomenon of rework is a serious problem. The related drawings and documents formed by each business are scattered throughout the hands of professional technicians and the version is confusing, lacking standardization and unified management and so forth.

Therefore, to solve the problems existing in the business stages of production exploration, mining planning and design, survey and acceptance of Fujian Makeng Iron Mine, based on the concept, connotation, characteristics, architecture and technical requirements of the mining technology collaboration platform proposed in Section 4, this case study first performed a requirement survey and analysis of the present situation of the Fujian Makeng Iron Mine mining production process, including the organizational structure of all participants, business and business posts, business processes,

business post responsibilities and input and output data under business post responsibilities; second, the design and development of the mining technology collaboration platform of Fujian Makeng Iron Mine were performed; finally, the operation and implementation of the mining technology collaboration platform of Fujian Makeng Iron Mine were carried out.

5.1. Requirement Survey and Analysis

The requirement survey and analysis for the R&D and implementation projects of the mining technology collaboration platform of Fujian Makeng Iron Mine are divided into two phases. In the first phase, through face-to-face interviews, the participants' organizational structure, professional duties, the input and output data under the professional duties and business processes are thoroughly understood; additionally, the business contents and business processes involved in geology, surveying and mining, as well as the application of three-dimensional mining software in various businesses are clarified; then, the problems existing in the requirement survey are analyzed and sorted out and the current situation and existing problems of requirement survey are discussed and confirmed by the focused discussion confirmation method to form a requirement survey report. In the second stage, based on the requirement survey report formed in the first stage, combined with the application characteristics of mine digitalization and informatization, the application technical standards, data management standards and business process standards that meet the mining technical requirements of Fujian Makeng Iron Mine are summarized and formulated, including the data coding system, data management standards, geological business process specifications, surveying business process specifications and mining business process specification.

This requirement survey and analysis involved six participants, including Fujian Makeng Mining Co., Ltd. and five construction units, involving a total of 9 departments and 21 departments and the organization structure of the mining technology posts in Fujian Makeng Iron Mine can be found in Reference [54] and Figure S1. Through the requirement survey and analysis of the above two stages, the existing business processes are reengineered to form the documents of the geological business process specification, survey business process specification and mining business process specification of Fujian Makeng Iron Mine [55–57]. On the basis of the standardized business process, the organizational structure of the mining technology post for Fujian Makeng Iron Mine after the organizational structure reengineering is formed, as shown in Figure 4. Based on the standardized business processes and the new organizational structure of mining technology posts, the duties of each professional post and its input and output data are defined. The surveying business standardization process includes 10 sub-business specification processes, such as a surface control survey, land acquisition survey, topographic survey, shaft and laneway engineering control survey and shaft and laneway engineering survey; the geological business standardization process includes 14 sub-processes, such as prospecting design, drilling logging, laneway logging and geological modeling; the mining business standardization process includes 14 sub-processes, such as mine area division, level division, stope division, development design, mining and cutting design and short hole design. The orebody modeling business standardization flow chart is shown in Figure 5 and the duties and the input and output data of each post in the orebody modeling business process are shown in Table 1.

Table 1. The duties and the input and output data of each post in the orebody modeling business process.

No.	Professional Post	Duty of Professional Post	Input Data	Output Data
1	Geological interpretation engineer	Geological interpretation	Borehole database, pit exploration database, laneway logging map	Geological interpretation line
2	Head of geology for Fujian Makeng Iron Mine	Review geological interpretation line	Borehole database, pit exploration database, laneway logging map, geological interpretation line	Postreview geological interpretation line
3	Deputy director engineer of geology	Review geological interpretation line	Borehole database, pit exploration database, laneway logging map, geological interpretation line	Postreview geological interpretation line
4	Geological modeling engineer	Orebody Modeling	Borehole database, pit exploration database, laneway logging map, geological interpretation line	Orebody model
5	Director of the digitization center	Review the orebody model	Borehole database, pit exploration database, laneway logging map, geological interpretation line, Orebody model	Postreview Orebody model
6	Vice-chief engineer of geology	Review the orebody model	Borehole database, pit exploration database, laneway logging map, geological interpretation line, Orebody model	Postreview Orebody model

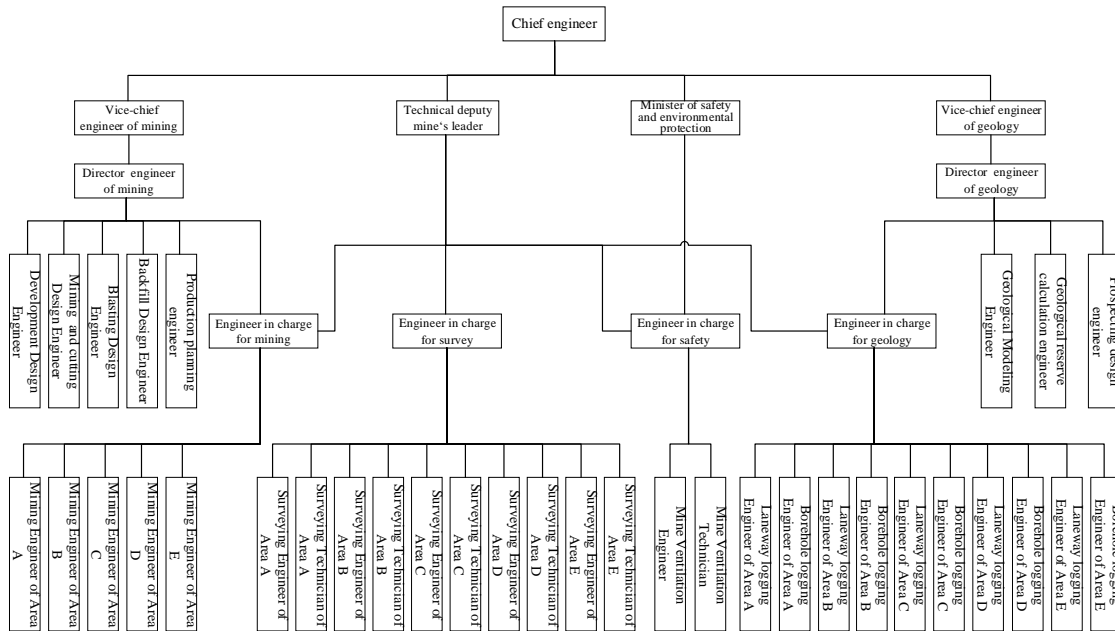


Figure 4. The new organizational structure of the mining technology post for Fujian Makeng Iron Mine.

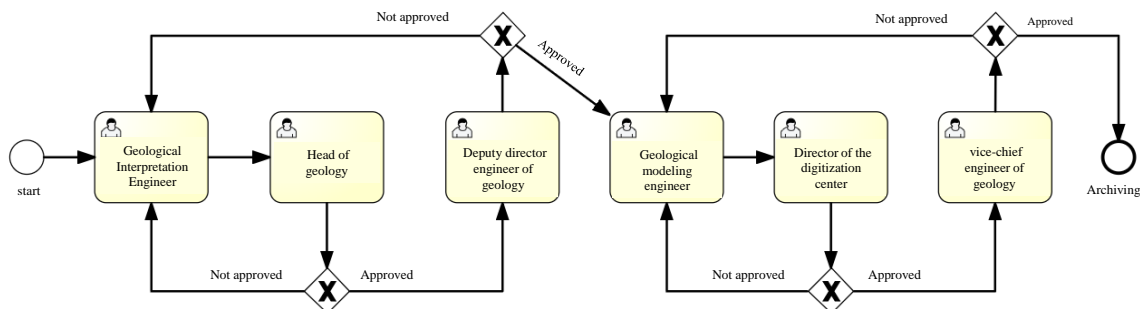


Figure 5. The Orebody modeling standardization business process.

5.2. Research and Development of MTCP

According to the concept, connotation, characteristics, architecture and technical requirements of the mining technology collaboration platform in Section 4 combined with the results of the requirement survey and analysis, the mining technology collaboration platform is developed.

The hardware and software environments for the development and implementation of the MTCP include the following—(1) a server with 512G memory, 600G*12 + 300G*8 hard disk, RAID6; and (2) the software environments of the server include Windows server 2012, PostgreSQL 9.3.14, Tomcat 6.0.36 and jdk1.6.0_38. The client browser for this R&D and implementation support is IE 8 and above, Chrome, Mozilla Firefox and the business software is DIMINE, iVent and iSchedule of Changsha Digital Mine Co., Ltd. (Changsha, China).

The research and development of the mining technology collaboration platform include the design and development of the mining technology collaboration platform management side, the design and development of the database and the transformation of the business software; its composition and relationship are shown in Figure 6. The mining technology collaboration platform is supported by information technology, such as the Internet network, through the mining technology collaboration platform management side, all the businesses, such as geology, surveying and mining, are carried out in the form of business processes and according to the business process and the information and authority of the role, the business software connected to the mining technology collaboration platform management side through the standard interface and the Internet is started to process and manage the technical businesses, such as geology, surveying and mining and the data required by the mining

technology collaboration platform management side and each business software comes from the database and the generated data is stored in the database, forming an organic whole composed of the mining technology collaboration platform management side, the business software and the database.

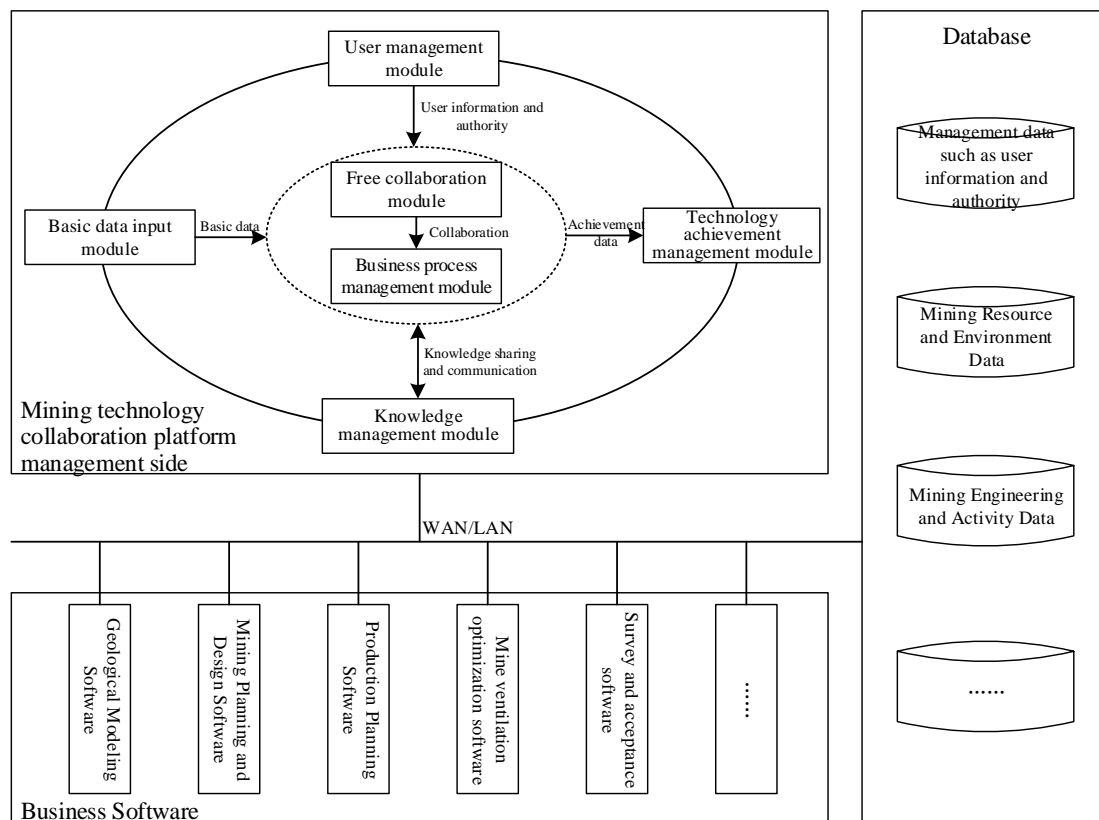


Figure 6. The composition and its relationship diagram of MTCP.

5.2.1. Mining Technology Collaboration Platform Management Side

The mining technology collaboration platform management side is based on the business process management module, which processes and manages the business processes of geology, surveying and mining that are included in the mine’s whole life cycle, including the definition, configuration, creation, initiation, to-do reminders, business processing, business flow, submission, approval and archiving of business processes; the external basic input data, such as the geology, surveying and mining, required for part of the business process in the business process flow process is input through the basic data input module; the information of user, function authority and data authority in the business process management module comes from the user management module; business processing on each business process node in the business process management module can realize two or more personnel from each participant, department and professional post through the free collaboration module to complete the business collaboration across time and space and multidisciplinary; the business process is created and initiated in the business process management module and is filed in technology achievement management module after the flow, approval and completion; in the process of the business process flow, the knowledge management module can be used to share and exchange the business technology knowledge. The relationship diagram of each module is shown in Figure 6. The technical framework of the mining technology collaboration platform management side adopts a multi-layered separation technology architecture, including the data layer, the data access layer, the business logic layer, the view layer. The data layer uses PostgreSQL database management system to store data; the data access layer accesses database through MyBatis; The logic layer uses the SpringBoot technology framework to process the business logic of each application; the view layer uses front-end technology architectures such as HTML, HTMLs, CSS3 and Vue to separate the front-end and back-end

code and display different application views for the user. The interface effect of the mining technology collaboration platform management side is shown in Section 5.3.

5.2.2. Transformation of Business Software

Based on the architecture, composition and relationship diagram of the mining technology collaboration platform, as shown in Figures 2 and 5, the business software not only needs to be connected with the business software interface standard provided by the management side of the mining technology collaboration platform but also the interoperability and sharing of the data in the business process based on the business software is realized through the standardization of the data processing and database storage. The purpose of the business software interface standard provided by the mining technology collaboration platform management side is to connect business software from different manufacturers and different professions to realize digital processing of various technical businesses in the process of the mine's whole life cycle business process flow.

However, the existing three-dimensional mining software at home and abroad is a click application, including geological modeling and resource evaluation, mining planning and design, survey and acceptance and other business functions and the data storage of three-dimensional mining software from different manufacturers uses their own defined data format and their own proprietary storage format files. Clearly, the existing business software involved in the mine's whole life cycle cannot meet the requirements of the mining technology collaboration platform except for the business functions. Therefore, based on the interface standards and data access, the business software involved in the whole life cycle of the mine is improved accordingly.

Based on the architecture, composition and the relationship between the components of the mining technology collaboration platform, the business software interface standard design of the mining technology collaboration platform management side includes the user ID, collaboration, editability, business process ID, business ID and whether it is a technical achievement. The business software interface standard of this R&D and design adopts the URL custom protocol interface standard, including the custom protocol and the parameters passed. The following describes a URL custom protocol interface standard with a specific example:

```
{
mine://
userid=00IT0001A10000000411
&token=5ec688c9-d508-4c3c-ae5c-adeb9ec27082
&ismytodo=true
&allowedit=true
&processid=304d07ffcd3f4f80851c80300c366823
&businessid=6855dc98-a750-49ce-afba-64dce85313ee
&isresult=false/
}
```

where "mine" is a custom URL protocol for locating the installation location of the business software; "userid" is a user ID with uniqueness; "token" is a token to verify the validity of the user's identity; "ismytodo" is used to indicate whether the user of the userid is responsible for the business or cooperates to complete the business; "allowedit" means whether the user has editing rights; "processid" represents the business process ID; "business id" denotes the business ID of the business process node; "isresult" indicates whether the business process is an archived technical result and the business software can load the result data of its archived moment by this parameter.

Based on the business software interface standard of the mining technology collaboration platform management side, combined with the idea of the business process and data interoperability and

high sharing, the business software is reformed accordingly, as follows—(a) the two parameters of “userid” and “token” in the business software interface standard require that the business software has a user login access control function; (b) the four parameters of “allowedit,” “processid,” “businessid” and “isresult” determine that the business software has a configuration function, which configures the business process flow, business software and its functions under its authority, as well as the input and output feature classes and loads the corresponding data; (c) data interoperability and high sharing require data standardization and database storage, in which the feature class of the data standardization is shown in Table 2. Therefore, the transformation of the business software includes user login and access control, process and standardization of business processing for the business software, configurability of the business workflow and its corresponding business software functions, standardization of business data and database storage of data. The use case diagram is shown in Figure 7 and the sequence diagram is shown in Figure 8.

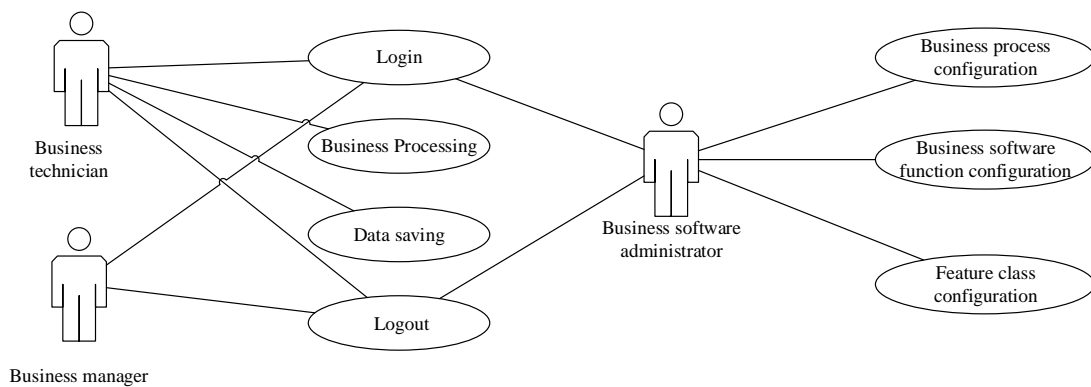


Figure 7. The use case diagram for business software transformation.

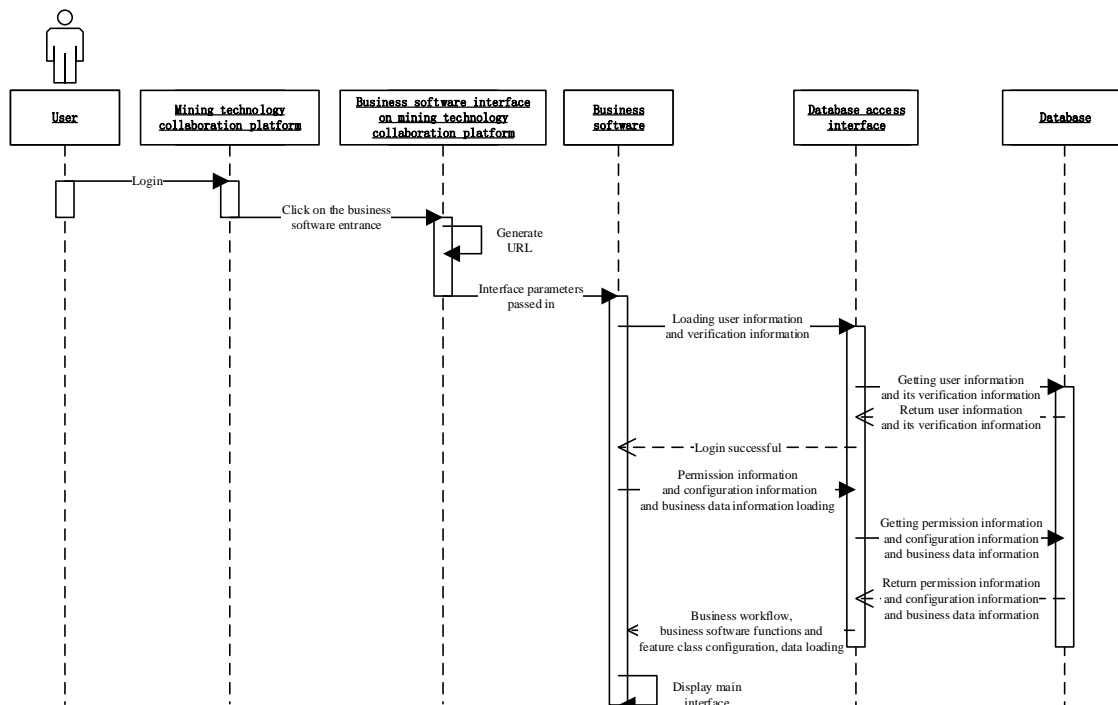


Figure 8. The sequence diagram for business software transformation.

Table 2. The feature group and feature class.

No.	Feature Group	Feature Class
1	Exploration line	Exploration line
2	Mining right	Mining right boundary line, Mining right boundary model
3	Engineering point	Control point, Survey point, Setting out point
4	Engineering boundary	Laneway measured waistline, Shaft and laneway engineering measured centerline, Laneway floor measured centerline, Shaft measured centerline, Shaft and laneway engineering design centerline, Shaft design centerline, Laneway engineering design centerline, Laneway design double line, Goaf boundary line, Land acquisition boundary line, Mine heap boundary line, Topographic status line, Chamber design centerline, Chamber roof measured centerline, Chamber floor measured centerline, Chamber measured contour line, Chamber design contour line
5	Engineering entity	Stope model, Goaf model, Stope design model, Shaft and laneway engineering design model, Shaft and laneway engineering measured model, Mine heap model, Surface model, Mining Area Model, Level model, Retaining wall model
6	Geological entity	Orebody model, Rock model in orebody, Surrounding rock model, Fault model, Orebody delineation model, Rock delineation model in orebody, Surrounding rock delineation model, Fault delineation model
7	Geological interpretation line	Geological interpretation line, Delineation interpretation line, Plane geological interpretation line, Profile geological interpretation line, Plane orebody interpretation line, Plane interpretation line of rock model in orebody, Plane surrounding rock interpretation line, Plane fault interpretation line, Profile orebody interpretation line, Profile interpretation line of rock model in orebody, Profile surrounding rock interpretation line, Profile fault interpretation line
8	Borehole database	Borehole database, Design borehole database, Pit exploration database
9	Engineering dimensioning	Shaft and laneway engineering footage line, Shaft and laneway engineering dimensioning point
10	Block model	Block model
11	Mine ventilation model	Mine ventilation model
12	Process data	Filtration borehole database, Sample-length composite borehole database, Design borehole trajectory line, Validity check data, Open line data, Laneway sampling line, Trend point data, Model slice contour line, Model intersection line, Model partitioning aided data, Section contour line, Retaining wall position line, Exploration line profile data,
13	Drawing and document	Laneway logging map, Design borehole plan map, Design borehole profile map, Monthly report on hydrological monitoring, Hydrogeological plan map, Shaft and laneway engineering measured map, Geological plan map, Geological profile map, Development design drawing, Mining and cutting design drawing, Shallow-hole stope design drawing, Medium-length hole stope design drawing, Large diameter deep hole stope design drawing, Backfill design drawing
14	Blasthole	Position line of a row of blasthole, A row of blasthole
15	Ore reserve table	Geological reserve table, Level ore reserve table, Goaf ore reserve table, Stope ore reserve table, Stope engineering ore reserve table, Stope production ore reserve table

5.2.3. Database

To realize the interoperability and sharing of business data among business software, it is necessary to standardize the business data, that is, before the business data is stored in the database, all business data objects involved are grouped into groups, that is, feature groups and then the business data objects are decomposed into minimum business data units, that is, feature classes; the concretization of feature class, that is, feature. Finally, the business data is stored in the database with the feature as the minimum management unit. The research and development of the mining technology collaboration platform of Fujian Makeng Iron Mine involve the feature group and class, as shown in Table 2. A total of 70 tables were designed using the PostgreSQL database, of which the orebody model and geological interpretation line data table are shown in Tables 3 and 4.

Table 3. Design of data table for orebody model.

No.	Field Name	Field Code	Field Type
1	ID of Orebody model	Uuid	uniqueidentifier
2	Orebody name	Name	varchar
3	Orebody number	OrebodyNumber	int
4	Mineral resources species	OreClass	varchar
5	Ore type	OreType	varchar
6	Ore volume	Volume	double
7	Ore weight	Weight	double
8	Description	Description	varchar
9	Whether it is a delineation model?	IsDelimitationModel	bit
10	ID of Work site	WorkPlace ID	varchar
11	Orebody model ID	Shell ID	uniqueidentifier
12	Orebody modeling business process ID	Workflow ID	varchar
13	Is it approved?	ApprovalFlag	integer
14	Start version number	VerFrom	bigint
15	End version number	VerTo	bigint

Table 4. Design of data table for geological interpretation line.

No	Field Name	Field Code	Field Type
1	Geological Interpretation Line ID	Uuid	uniqueidentifier
2	Name of geological interpretation line	Name	varchar
3	Type of geological interpretation lines	GeologicalInterpretationLineType	varchar
4	Number of Geological body	GeologicalBodyNumber	int
5	ID of Work site	WorkPlace ID	varchar
6	Line ID of Geological Interpretation Line	LineID	uniqueidentifier
7	Orebody modeling business process ID	Workflow ID	varchar
8	Is it approved?	ApprovalFlag	integer
9	Start version number	VerFrom	bigint
10	End version number	VerTo	bigint
11	Description	Comment	varchar

5.3. Project Implementation

5.3.1. Implementation of Overall Business Process

According to the results of the requirement survey and analysis for Fujian Makeng Iron Mine, the hierarchical decomposition diagram of the business process model of the whole life cycle for Fujian Makeng Iron Mine is shown in Figure 9, which is divided into the following three layers—A0 layer, A1 layer and A2 layer. The relationship between the A2 layer and the A3 layer of Fujian Makeng Iron Mine is shown in Figure 10. As shown in Figure 9, the business process of the A1 layer for Fujian Makeng Iron Mine is based on geology, mining and surveying. The business process of Layer A2 is further decomposed on the basis of the business of Layer A1 and the business process of Layer A3 is

further refined on the basis of the business of Layer A2. The 38 standardized business processes of the Fujian Makeng Iron Mine are the business processes of the A3 layer. The relationship between the A2 layer and the A3 layer is shown in Figure 10.

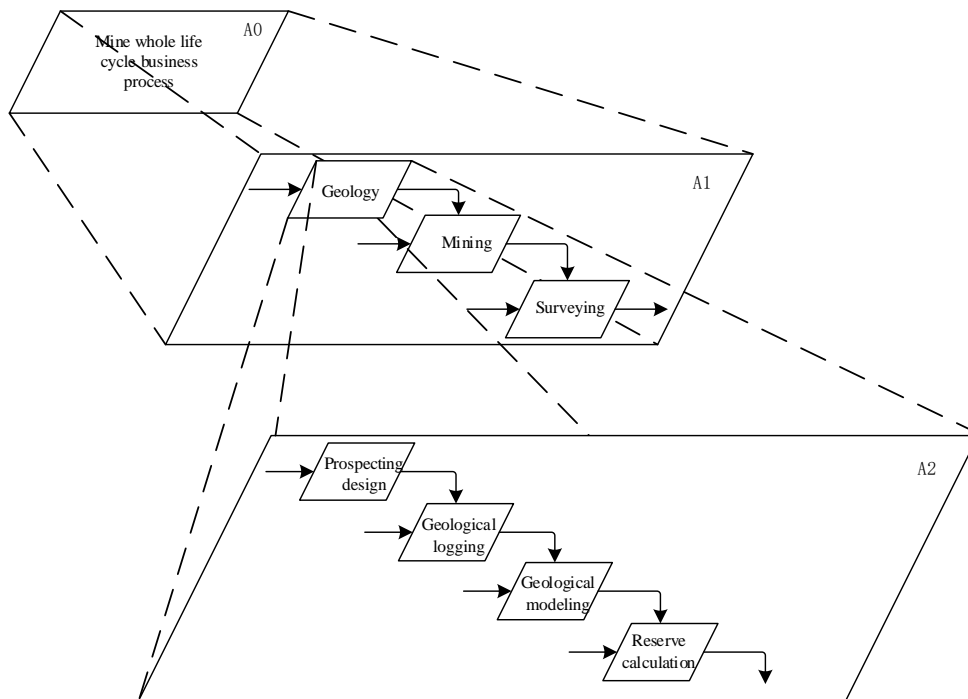


Figure 9. The hierarchical decomposition diagram of business process model of Fujian Makeng Iron Mine based on IDEF0.

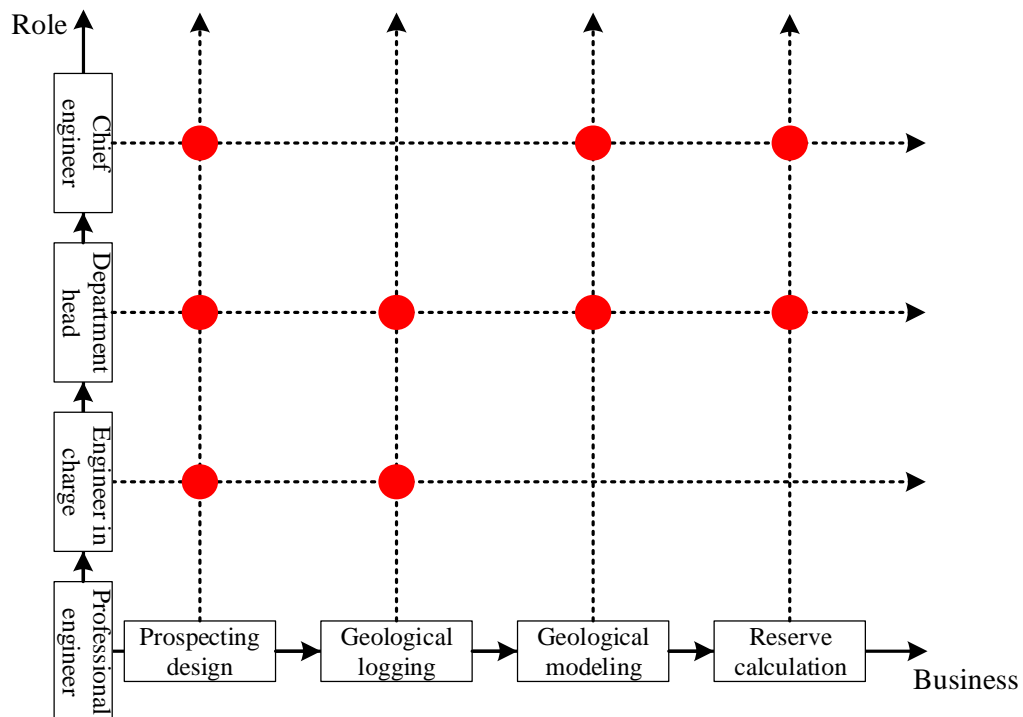


Figure 10. Diagram of business process flow between A2 and A3 layers of Fujian Maikeng Iron Mine.

Based on the new organizational structure, standardized business process, clear professional post duties and the input and output data formed by the requirement survey and analysis of Fujian Makeng Iron Mine, the participants' organizational structure and user information of the developed mining technology collaboration platform are input. On this basis, the 38 standardized business processes of Fujian Makeng Iron Mine are defined and configured. The configuration includes the roles of the business process nodes, the users corresponding to the roles, the businesses corresponding to the roles, the work areas, business software and its functional rights and the input and output data under the duties of the business posts.

On the basis of the completion of 38 standardized business process definitions and configurations, 38 standardized business processes are respectively created, initiated, processed, flowed, approved, submitted and filed by the geological, surveying and mining professional business in the same working site according to the mode of the A2 layer business process flow. The A1 layer business process involved in the whole life cycle of Fujian Makeng Iron Mine is generally carried out according to geology → mining → surveying. The business process of the A2 layer in geology is according to prospecting design → geological logging → geological modeling → reserves calculation. The relationship between the A2 layer and the A3 layer business process flow is explained in detail by Figure 10, of which the red dot is the corresponding role of the business of each process node of 38 normalized business processes. The flow relationship of the A2 layer business process of Fujian Makeng Iron Mine is as follows:

- (1) According to the prospecting plan, the standardized business process of prospecting design for a working site was created and initiated. The prospecting design engineer started the DIMINE software through the business software entrance on the mining technology collaboration platform and completed the prospecting design work under his job duty and saved the data of the prospecting design results (including design borehole database, design borehole plan and profile map) to the database and submitted the prospecting design business form. According to the standardized business process of prospecting design, it flows to the supervisor, department head and chief engineer of the prospecting design successively. The supervisor, department head and chief engineer review the prospecting design results data according to their job duties. If they do not meet the requirements, they can be directly rejected and returned to the prospecting design engineers until the results data is approved and archived.
- (2) The resulting data of prospecting design (design borehole database, design borehole plan and profile) are used to guide on-site prospecting construction and data such as opening, inclination, lithology and grade are obtained during the prospecting construction process and corresponding sample tests. On this basis, through the creation and initiation of standardized business processes of geological logging, geological logging engineer started geological modeling software through the business software entrance on the mining technology collaboration platform and completed the geological logging work under his job duty and the result data (including borehole database, pit exploration database and laneway logging map) are saved to the database. In accordance with the standardized business process of geological logging, it flows to the supervisor and department head of the geological logging successively. The supervisor and department head review the geological logging results data according to their job duties, until the results data is approved and archived.
- (3) The relevant personnel of geological modeling received the reminder of the standardized business process of geological logging at work site A and created and initiated the geological modeling standardization business process. The geological modeling engineer started the geological modeling software through the business software entrance on the mining technology collaboration platform and the geological modeling software automatically loaded the result data of geological logging from the database according to configuration information (including borehole database, pit exploration database and laneway logging map). The detailed business processing, transfer, approval, submission and archiving of the geological modeling business process can be observed in the example of the orebody modeling business process.

- (4) The relevant personnel of the reserve calculation received the reminder of the standardized business process of geological modeling at work site A and created and initiated the reserve calculation standardized business process. The reserve calculation engineer started the geological modeling software through the business software entrance on the mining technology collaboration platform and the geological modeling software automatically loaded the result data of geological modeling from database according to configuration information (including borehole database, pit exploration database, orebody model, level model, stope model and shaft and laneway engineering model) and completed the reserve calculation work under his job duty. The result data (including block model, level ore reserve, stope ore reserve, stope engineering ore reserve) are saved to the database. According to the standardized business process of reserve calculation, it flows to the department head and chief engineer of the reserve calculation successively. The department head and chief engineer review the reserve calculation results data according to their job duties, until the results data are approved and archived.

The relevant personnel in mining planning and design received reminders of the completion of the standardized business processes for geological modeling and reserves calculation and created, initiated and completed the business processes for mining planning, mine development design, mining and cutting design in sequence. The relevant personnel in surveying received reminders of the completion of the standardized business processes for mining planning and design and created, initiated and completed business processes such as the underground control survey and construction lofting. Therefore, the 38 business tasks involved in the Fujian Makeng Iron Mine are strictly handled and managed in accordance with the business process flow method and the organizational structure of the participants involved in the process is optimized and flattened; additionally, the duties of all professional post and its input and output data are clarified and the business data are standardized. The centralized access, interoperability and high sharing of the business data and the high-speed flow of the business are realized.

5.3.2. Implementation of the Orebody Modeling Business Process

The 38 standardized business processes under the geology, surveying and mining of the Fujian Makeng Iron Mine have the same flow mode of business processes except for the types of businesses, business processes and business software. To further illustrate the high-speed flow and collaboration between businesses and the interoperability and high sharing of data among the 38 standardized business processes on the mining technology collaboration platform for Fujian Makeng Iron Mine, the following is an example of the operation and implementation of the orebody modeling business process. The details are as follows:

- (1) Definition and configuration of orebody modeling business process

According to the results of the requirement survey and analysis, including the standardized orebody modeling business process, the job duty of each process node and its input and output data, the business process of orebody modeling in Fujian Makeng Iron Mine is defined and the roles of each business process node, the users corresponding to the roles, the roles corresponding to the business software and its functions and business data are configured. The professional post duty and its input and output data tables and the business flow charts of the orebody modeling are shown in Table 1 and Figure 5, respectively.

- (2) Creation and initiation of the orebody modeling business process

The creation of the orebody modeling business process is mainly to create business forms and determine the site and content of the work. This task is to complete the construction of the orebody model of the 100 m level, 200 m level and 300 m level of the E mine area of Fujian Makeng Iron Mine and submit the created orebody modeling business form and initiate the orebody modeling business process, as shown in Figure 11.

(3) Geological interpretation engineer conducts geological interpretation

The geological interpretation engineer receives reminders of to-do items, signs the to-do items and starts the geological modeling software under his/her authority through the business software entrance on the business form and then automatically loads the input data under his/her authority from the database (see Table 1) for geological interpretation.

Since the geological interpretation of the orebody modeling business process involves a total of 15 levels, including 100 m level, 200 m level and 300 m level and 12 sublevels between the three levels, the geological interpretation workload is large. Therefore, to increase the speed of the progress of geological interpretation work, the geological interpretation engineers, through the mining technology collaboration platform management side of the free collaboration module, set up a free collaboration group to work together to complete the geological interpretation work. The free collaboration group provides a unified and data-sharing digital working environment for all collaborators through the mining technology collaboration platform and the team members can communicate with each other through instant messaging tools integrated in the mining technology collaboration platform, which changes the traditional decentralized collaboration mode and data exchange based on paper or electronic documents and changes the problem that communication information in the traditional collaboration process cannot be effectively preserved. In the free collaboration group, the approvers and the follow-up users of the business achievement data can be added to enable the relevant personnel to timely understand and grasp the business work, business progress and achievement data and to give timely advice and guidance on the problems existing in the process of business collaboration to avoid rework due to noncompliance and to accelerate the completion of the business collaboration and review of the achievement data.

This free collaboration group includes not only those who directly participate in the collaboration but also the approvers of the geological interpretation line, such as the head of geology for Fujian Makeng Iron Mine, the deputy director engineer of geology, the geological modeling engineer, the director of the digitization center and the vice-chief engineer of geology. The members of the free collaboration group who have editing rights are the collaborators, while those without editing authority are the follow-up reviewers and geological modelers. In addition, during the collaboration process, the free collaboration group can communicate technical issues through instant messaging tools, where the communication records are archived as the business process is archived.

When all the collaborators complete the geological interpretation work, the geological interpretation engineer approved the collaborators' achievement data and submitted the business form of the mining technology collaboration platform management side and the business form flowed to the head of geology for Fujian Makeng Iron Mine. The collaborative achievement data of geological interpretation is the geological interpretation line, as shown in Figure 12.

(4) The head of geology for Fujian Makeng Iron Mine reviewed the achievement data of the geological interpretation engineer.

The head of geology for Fujian Makeng Iron Mine received the reminder of the to-do items, signed and received the to-do items and started the geological modeling software through the entrance of the business software on the business form and automatically loads the input data and the achievement data under his authority (see Table 1) to review the achievement data (that is, geological interpretation line) of the geological interpretation engineer.

The head of geology for Fujian Makeng Iron Mine reviewed the achievement data of the geological interpretation engineer (i.e., geological interpretation line). If it met the requirements, the head of geology for Fujian Makeng Iron Mine would select the approval option on the business form

of the mining technology collaboration platform management side as “Agree,” then submit the business form; the business form then flowed to the deputy director engineer of geology; if it does not meet the requirements, the approval option on the business form is selected as “Reject” and the reasons for the noncompliance are explained in the approval comments column, then submit the business form and the business form is returned to the geological interpretation engineer and the geological interpretation engineer modifies the geological interpretation line based on the review opinion.

- (5) The deputy director engineer of geology reviewed the achievement data of the geological interpretation engineer.

The duty of the deputy director engineer of geology is the same as the head of geology for Fujian Makeng Iron Mine. They are all reviewing the achievement data of the geological interpretation engineer (that is, the geological interpretation line). Therefore, see list (4) for details.

- (6) The geological modeling engineer conducted orebody modeling based on the approved geological interpretation line.

The geological modeling engineer received reminders of to-do items, signed and received the to-do items, started the geological modeling software through the business software entrance on the business form and automatically loaded the input data and achievement data under his/her authority (see Table 1) for orebody modeling.

Geological modeling can also form a free collaboration group by the free collaboration module and the free collaboration team can collaborate to complete the orebody modeling work; for details, see the free collaboration in the geological interpretation work. Based on the input data, the geological modeling engineer completed the construction of the orebody model through the two process steps of orebody modeling and model optimization detection and saved and submitted the achievement data (i.e., the orebody model) to the database. The resulting data are shown in Figure 13. The geological modeling engineer submitted the business form of the mining technology collaboration platform management side and the business form flowed to the director of the digitization center.

- (7) The director of the digitization center reviewed the achievement data of the geological modeling engineer.

The director of the digitization center received the to-do reminder, signed and received the to-do items, started the geological modeling software from the business software entrance on the business form of the mining technology collaboration platform management side and automatically loaded the input data and the achievement data under his/her authority (see Table 1) to review the achievement data (i.e., the orebody model) of the geological modeling engineer.

If it met the requirements, the director of the digitization center will select the approval option on the business form of the mining technology collaboration platform management side as “Agree,” then submit the business form; then, the business form flowed to the vice-chief engineer of geology; if it does not meet the requirements, the approval option on the business form is selected as “Reject” and the reasons for the rejection are explained and the business form is submitted; then the business form is returned to the geological modeling engineer and the geological modeling engineer makes the targeted modifications to the review comments and instructions and resubmits the model after the modification is completed.

- (8) The vice-chief engineer of geology reviewed the achievement data of the geological modeling engineer.
- (9) The duty of the vice-chief engineer of geology is the same as the director of the digitization center, that is, to review the achievement data (i.e., the orebody model) of the geological modeling engineer. Therefore, for details see list (7). When the vice-chief engineer of geology’s review opinion was “Agree” and he/she submits the business form, the orebody modeling business

process is completed and is entered into the technical achievements management module for archiving.

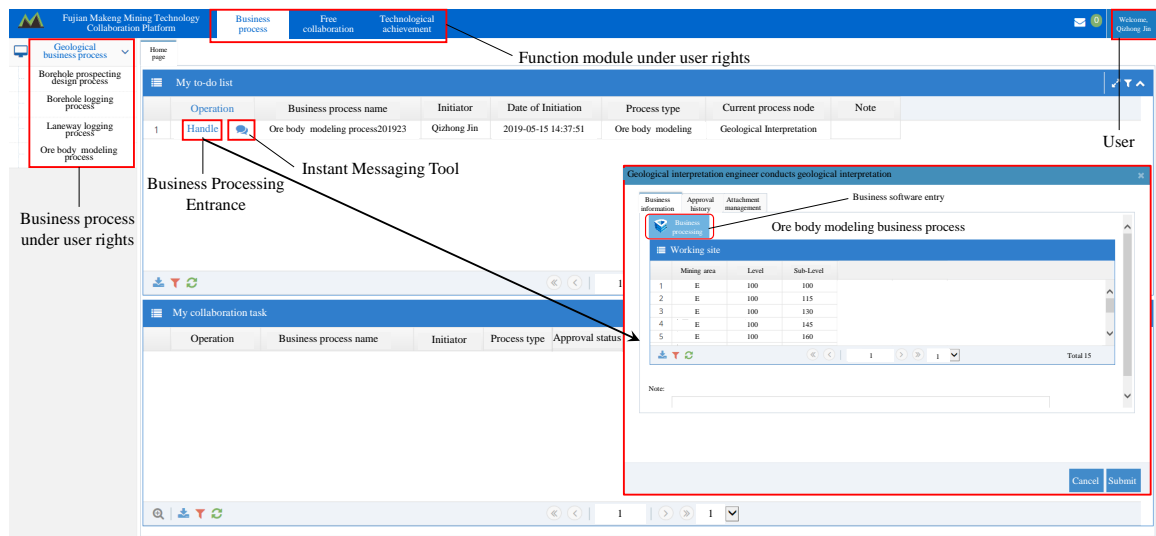


Figure 11. Initiation of ore body modeling business process.

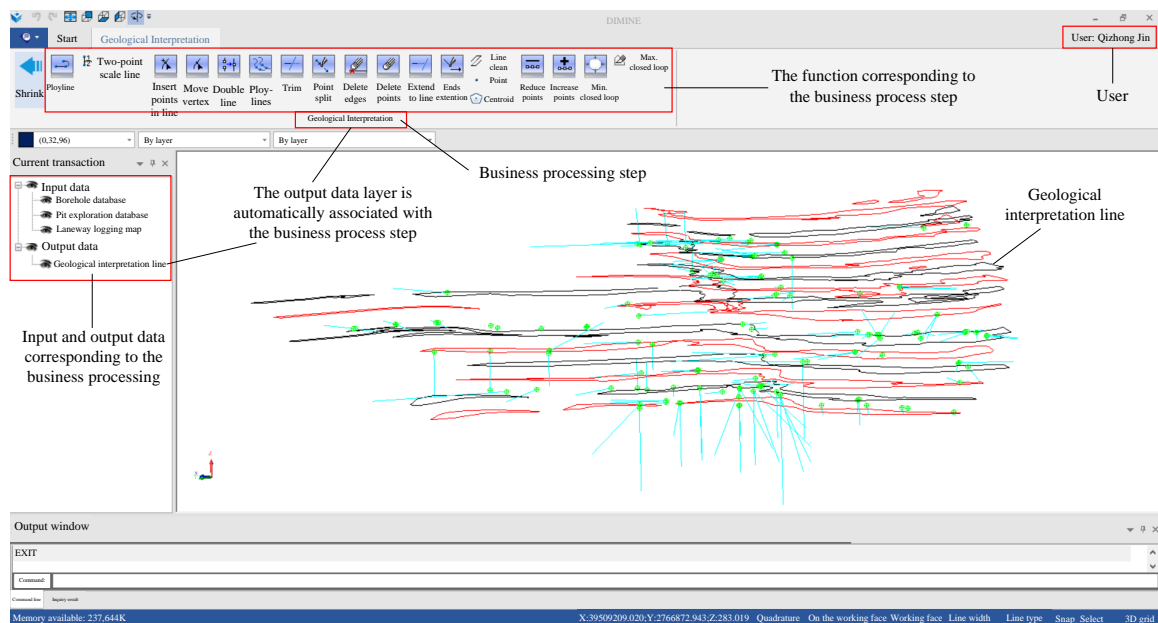


Figure 12. The geological interpretation line based on the geological modeling software.

A total of 38 standardized business processes involved in the Mining Technology Collaboration Platform for Fujian Makeng Iron Mine are defined, configured, created, initiated, flowed, approved and archived in accordance with orebody modeling business processes.

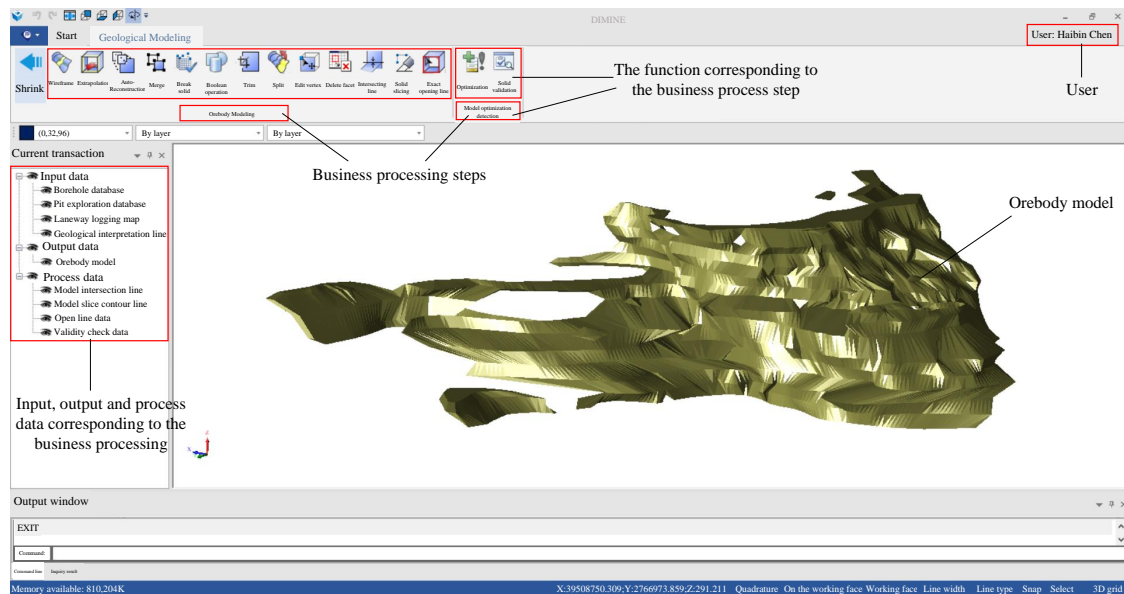


Figure 13. The orebody model based on business software.

5.4. Application Results

Based on the theoretical framework of mining technology collaboration platform proposed in this paper, taking Fujian Makeng Iron Mine as an example, the mining technology collaboration platform of Fujian Makeng Iron Mine has been developed and fully implemented and has been unanimously recognized by field technicians, engineers and leaders. Compared with before application, the results obtained are as follows:

- (1) The centralized storage of all data. Compared with traditional paper and electronic documents scattered in the hands of participants, departments and professional positions, it saves a lot of time and effort for technicians to collect large amounts of data before the business processing and ensures the integrity, accuracy, safety and the latest version of the data, so as to solve the problems of data faults, data loss and data version confusion under the traditional mode.
- (2) The standardized processing of all data. In the traditional mode, only the data results of the business or business phase are considered, which leads to the subsequent business obtaining the data that cannot be directly utilized and needs to be further processed into data that meets the requirements of the business. After data standardization processing, this paper can ensure that data is directly used by each business. It ensures the interconnection and high sharing of data among all participants, departments and professional posts and also saves the time and resources for further processing of data and solves the traditional problem of “information island.”
- (3) The high-speed flow between each business is through the standardized business process. The traditional functional management mode based on the division of labor theory makes the business process fragmented and the business flow is not smooth and extremely slow. Through standardized business processes, it ensures the smooth flow of business processes and the unity of objectives and interests of participants, departments and professionals, breaks the organizational boundaries between participants and departments and solves the problem that the participants and departments often conflict with each other in maintaining their own goals and interests under the traditional mode.
- (4) Its organizational structure was optimized and the duties of each position and its input and output data were clearly defined. Compared with the traditional “pyramid” organizational structure, which is characterized by overstuffed organization, low management efficiency and high cost

and unclear responsibilities of each post, which leads to the duplication of work content and work prevarication and so forth, by using information technology such as the Internet, this paper reduces the middle management, achieves flat management, improves its decision-making ability and reduces operating costs.

- (5) Through the research and development of the mining technology collaboration platform, it integrates geological, surveying, mining and other business and its required business software for Fujian Makeng Iron Mine and integrates all the involved participants, departments and professional positions, improving the across time and space and multidisciplinary collaborations ability of all participants, departments and professional posts.

Although the mining technology collaboration platform of Fujian Makeng Iron Mine developed under the theoretical framework of mining technology collaboration platform has made some achievements in information and management, it still needs to improve the fault tolerance and robustness of the mining technology collaboration platform, improve instant messaging tools and support the mobile and Web side to view the achievement data to view and review the data at any time and anywhere.

6. Conclusions

This paper first summarizes and analyzes the current status of China's digital mine construction and its existing problems and then, through summarizing and analyzing the problems existing in the development process of the AEC industry in its digitalization and informatization, it is found that the AEC industry and mining industry have similar problems in the process of digitization and informatization. In order to solve these problems, the AEC industry puts forward the concept of BIM and develops a series of collaboration platforms based on BIM concept. Therefore, this paper puts forward the theoretical framework of mining technology collaboration platform, including the concept, connotation, characteristics, architecture and related technical requirements, by referring to a series of collaboration platforms developed based on BIM concept and guided by MIM concept. On this basis, taking Fujian Makeng Iron Mine as an example, the mining technology collaboration platform of Fujian Makeng Iron Mine is developed, applied and implemented.

The R&D and application of the mining technology collaboration platform of Fujian Makeng Iron Mine shows that under the guidance of the theoretical framework of the mining technology collaboration platform proposed in Section 4 of this paper, with the help of information technology such as Internet and database, all data are standardized and centrally stored and all business flows at a high speed with standardized business processes and the post responsibilities and input and output data are clarified and all involved businesses, business software and participants, departments and professionals are integrated. Therefore, it saves a lot of time and resources for data collection and further processing before business processing; ensures the smooth flow of business, avoids problems such as overlapping work and serious rework; enhances the ability of all participants, departments and professional posts to collaborate across time and space and multidisciplinary; and also solves the problems of information and management such as information islands, information faults and blocked business processes in the current construction of digital mine in China. Finally, it also realizes centralized management of the business work, centralized control of business processes, centralized storage of business data, interoperability and high sharing of business data, reduced production costs of mining enterprises, improved work efficiency and the quality of mining enterprises and market competitiveness and provided guarantee for the safe, efficient production and sustainable development of mining enterprises.

Although the concepts, connotations, characteristics, architecture and related technical requirements of the mining technology collaboration platform proposed in this paper have been verified in the Fujian Makeng Iron Mine Project, the case in this paper is limited to production technology stage and the business software used is from the same manufacturer. Therefore, the theoretical framework of the mining technology collaboration platform proposed in this paper is only used as the basis for

the development of the theoretical system and the R&D and implementation of related products and the future research direction needs to be extended to other business phases of the whole mine life cycle and the business software is extended to other manufacturers.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2076-3417/9/24/5373/s1>, Figure S1: The previous organizational structure of Fujian Makeng Iron Mine.

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