Modeling Framework for Mining Lifecycle Management

Na Lu, Caiwu Lu, and Zhen Yang
Xi’an University of Architecture and Technology, Xi’an, China
Email: hr.luna@163.com, lucai@126.com, zhongdg@hotmail.com

Yishuang Geng
Center of Wireless Information Network Studies (CWINS), Worcester Polytechnic Institute, Worcester, MA, 01609, USA
Email: ygeng@wpi.edu

Abstract—In the development process of the information of the mining engineering, it is difficult to directly exchange and share information in the different phases and different application system, which causes the information isolation and information gap due to lack of unified data exchange standards and information integration mechanism. The purpose of this research is to build a modeling framework for mining lifecycle information management. The conception of mining lifecycle management (MLM) is proposed based on product lifecycle management (PLM) and Hall three dimension structures. The frame system of mining lifecycle management has been established by the application route of the information integration technologies and information standards. The four-layer structure of the realization of MLM system is put forward, which draws up the development method of MLM system. -The application indicates that the proposed theories and technologies have solved the problem of information isolation in different phases and application in mining engineering, and have laid a foundation for information exchange, sharing and integration in mining lifecycle.

Index Terms—Mining Information System; PLM; MLM; Standard

I. INTRODUCTION

The mining industry is changing from the traditional experience to quantitative analysis based on automatic direction science based. It aims at taking active measures to push the development of mine exploitation and development informatization process [1]. Currently, the related development has entered digital mine phase. Digital mine refers to the digital reproduction for unity and related phenomena of real mine in general sense. The core of digital mine is scientific and rational organization of information on various types of mines in a unified spatial and temporal framework, which manages and integrates massive heterogeneous spatial information resources of mine comprehensively, efficiently and orderly [2–3].

The Nolan’s stage model is proposed by an America expert of management information system (MIS) Richard Nolan. He argues that the information system was divided into six stages, including 1) initiation, 2) contagion, 3) control, 4) integration, 5) data administration and 6) maturity [4]. Between stage 3 and 4, an important transition occurs from managing the computer to data as a resource. Systems-development from stage 1 to 3 -was generally created as independent entities. At the beginning of stage 4, integration, a major effort is made to integrate existing information systems by using database and telecommunications technologies. The introduction of database technology drives the shift from traditional files supporting single applications to the design of logical databases supporting multiple applications during stage 5, data administration. Furthermore, information sharing requires a software environment in which computer programs can exchange data automatically regardless of software and data location. He recommends that before any MIS management needs to achieve growth, the first step is to identify what stage they are now involved.

According to Nolan’s stage theory, it can be concluded that the research on mine information construction is still in the early stage in China, which involves in initiation, contagion, and control stage. With the development of GIS, CAD and 3D visual modeling technology, the software companies have developed diversity software of different needs and the different hierarchy. For example, Canada, U.S. Australia and UK, have developed a series of 3D visual mining and application systems, including LYNX, Mintek, Gemon, Datemine and Surpac and some related software [5].

In the development process of the information of the mining engineering, due to lack of unified data exchange standards and information integration mechanism, it is difficult to directly exchange and share information in the different phases and different application system, which causes the information isolation and information gap. To realize the mining information integration, we must complement and implement to meet the actual needs of the various mining integrated technology [6–7].

The research on the method of mining information integration and management is done by researchers, who have developed information management systems. The
related studies are as follows: Huoran Sun has proposed that digital mine is characteristic of mine information integration, data sharing and visualization. Chonglong Wu presents that the key of digital mine construction integration creates subject data bases, which should be combined with MIS, DDS, ERP and OA technologies. Dewen Sun specializes in 3D data model, virtual reality technology and data warehouse. Yipeng Zhou has applied 3D panoramic technology and 3D simulation technology to construct digital mine.

The above research and application system are for one stage of mining engineer only; which is not related with overall solution of information creation, integration and sharing, through mining lifecycle management from requirement analysis, design, production, operation and maintenance.

Therefore, the purpose of this paper is to present a modeling framework for mining lifecycle information management. The framework holds the promise of seamless integrating all the information produced throughout all phases of a mining lifecycle. It makes mine highly effective, safe and green and increases continuously mine economics. The objective will be presented by: 1) The conception of mining lifecycle management (MLM) is proposed under the guidance of product lifecycle management (PLM) and Hall three dimension structure. 2) The frame system of mining lifecycle management has been established by using the route of the information integration technologies and information standards. 3) The four-layer structure realization of MLM system is put forward, which draws out the development method.

II. THE MLM SYSTEM PROPOSED MODEL FRAMEWORK

MLM is inspired by PLM in the manufacturing industry. PLM is generally defined as a strategic business approach for the effective management and using corporate intellectual capital [8]. PLM systems are being accepted - for managing all information about a corporation’s products throughout the products’ full lifecycle. It is a strategic business approach for the effective creation, management and using corporate intellectual capital, from a product’s initial conception to its retirement [8], which runs through product lifecycle including requirement analysis, design, development, test, execution, evaluation to maintenance and disposal.

After analyzing PLM concept, the following section presents the concept of Mining Lifecycle Management (MLM) modeling.

MLM modeling supports interchanging and sharing mining content of different phases and different fields. The content includes geometry, virtual structure, virtual behavior and process information which run through mining lifecycle consisting of requirement analysis, design, and, production, operation and maintenance.

The purpose of MLM modeling is to support collaborative mining design, to support mining lifecycle content creation, management, exchange and sharing.

In the above concept, the content means all the digital resources and non-digital resources such as models, data, processes, resources, tools and the interrelated relationships.

By contrast with Soft Systems Methodology (SSM), the Hall’s 3D structure is called Hard System Methodology (HSM), which was proposed by American systems engineer experts A. D. Hall in 1969. The HSM divides large complex systems into seven phases, which takes into account the completion of the every phases and requirement for the various skills. The HSM three dimensions structure is composed of time dimension, logical dimension and knowledge dimension, shown as Fig. 1.

![Figure 1. Hall 3 dimensions structure](image)

Based on the theories of HSM, the methods of building 3D view MLM are put forward, including Prototype system view, organization view and time view. The 3D view supports the information interchangeability and shares among various phases and domains in mining lifecycle. The goal of the modeling framework is to overcome the information interoperability problems which exist in virtual prototype lifecycle information integration, process integration and system integration.

Lifecyle-oriented mining 3D model makes mining design in a collaborative environment because the 3D model provides a consistent and integrated mining information view for all the designers and producers. All of the project participants can work collaboratively through the 3D model. To build the 3D model, five factors must be considered: (1) mining lifecycle is very complex whose content includes mining lifecycles heterogeneous information, and people hope that mining lifecycle content comprises enough data; (2) people hope that they can pick up needed data and give up the uninterested data conveniently and quickly; (3) provide a generic repository of all mining information at all stage of the design process; (4) serve all mining description information to the MLM system by using a single, uniform information exchange protocol; and (5) support direct interoperability among different mining software and other interrelated systems where high bandwidth, seamless information interchange is needed. Based on the
above reasons, efficient and effective views are given highly.

In [9], concepts of digital models have been proposed by different authors and experts. Which includes the five concentric circle model, shown as Fig. 2, proposed by Professor Lixin Wu, and the seven layer model advanced by Dewen Sen, is shown as Fig. 3 [10]. Although the dissertation has effectively driven the development of concepts and the popularization of DM, it does not address the System Integration Solution through the mining lifecycle, and lack of the integration mechanisms from different project participants.

![Figure 2. Five concentric circle model](image)

A. Prototype System Dimension

Prototype system dimension can be regarded as simulation software components structure and behavior from aspect virtual prototype simulation in different phases of digital mine. Main theory of prototype system is divide digital mine construction information into digital mine information and dynamic behavior, and both of the entity and the behavior can be programmed as simulation software components [1].

Digital mine information model (DMIM) provides the core information through the whole mining lifecycle management, which supports collaborative platform between different engineers and project participants. The models should be provided with three characteristics: 1) the models are defined as parametric models; 2) the 2D/3D real-time parametric model is shown interactively; and 3) the models adopt non-graphical data report integration.

The applications of DMIM change the design process, which transforms geometric elements 2D design into 3D virtual design. Design work moves the design phase, which makes the designer focus on the product design instead of coordinating documents and specialty. DMIM makes sense of mining information integration, which is supported by software, including Medsystem, Vulcan, Minescape, Micro mine, Surpac, Datamine &Guide, GIS and other software [11].

![Figure 4. The 3 dimension view of MLM](image)

In recent studies of DMIM deployment, a number of advantages and challenges have been identified in practice. Experts have identified six advantages of using DMIM in the early conceptual stage: 1) Rapid visualization; 2) better decision support upstream in the project development process; 3) rapid and accurate updating of changes; 4) reduction of man-hours required to establish reliable space programs; 5) increasing communication across the total project development team (explores, designers, capital allocation decision makers, production entities, and producers); 6) enhancing confidence in completeness of scope.

Mining dynamic behavior’s task is to describe the process of information interaction in the time-domain, and the reaction of DMIM elements on interactive information.

The advantages reported from the adoption and use of DMIM into practice is clear proved that visions of benefits with ND-based DMIM technologies are becoming realized.

B. Organization Dimension

Organization ontology is used to explain who creates or modifies the content and the author belongs to which department. Mining engineer must be accomplished by the different function organization during the each phase in lifecycle management. In terms of information sharing and cooperation levels, organizational integration should be divided into three levels, including communication, coordination, and collaboration [12]. Throughout all the different stages of whole lifecycle, each longitudinal scope of management changes with the different responsibility but in the horizontal range, the expansions...
The process integration is a part of process management, which makes the process parallelized and restructured. Modeling based on the IDEF is an efficient way to realize process improved and restructured. In addition, workflow management is a tool for the overall planning process, in which makes the process standardized [14]. The way shown in Fig. 8 uses parallelizing process to integrate process. In the process, DMIM offers the core content, communication and collaboration platform is an important means for exchanging information. Therefore, the DMIM not only promote the time integration, but also provides a unified model for information exchange.

Figure 7. The relationship of the two processes

III. ARCHITECTURE FOR MLM IMPLEMENTATION

To validate that 3D view of MLM is a consistent and integral mining information view, a modular, Systematic and open assembly system for MLM implementation is developed. The system is based on computer technology including object-oriented, service-oriented programming and mining life cycle management (MLM) specification. The system supports traditional software application and Distributed system architecture; meanwhile, it provides data exchange based on files and multi-model data access. Under the instruction of modern life cycle management methodology [15], it is a structural description of process information, organizational information, structural information, behavioral information and content/knowledge information in the mining life cycle model.

Figure 8. Integrated process
1) Project information portal (PIP) layer: project information portal (PIP), on the basis of project participants’ information and centralized knowledge management, supports the single project information portal on the web, which adopts the interoperability, collaboration and unified environment for the parties. Using PIP which is based on interactive files management, the information exchange between user and server is more efficient and effective. This architecture is Internet-oriented, which services are convenient and designed for the internet users and developers in order to use and develop user-define application.

2) Core application layer: This layer provides services for the application software involving in different sub-system at every life cycle phase, such as analysis designing software, 3D visual modeling software, production management software, OAS, MIS, DSS and ERP system. The layer efficiently integrates software systems, such as 4d system.

3) Data modeling layer: This layer is a process of reading, storing, extracting, integrating, managing, exchanging, and sharing mining information in different lifecycle phase; meanwhile, the related information will generate sub-models. The models are in phase-oriented sub-models including analysis system, design system, produce system and operate system as well as specific application, such as OAS, MIS, DSS and ERP systems.

It is clear that each sub-system operates by using its own data structure. For the DMIM mentioned above, the data in the integrated automation system should have a standard format and be processed in a standard way in order to enable seamless integration of sub-systems. For example, when we want to evaluate the mine safety status on line, the information comes from several different sub-systems, that is, the environment monitoring system, the ventilation control system, the mine pressure monitoring system, the underground water outburst and water level monitoring system.

4) Data warehouse layer:
This layer stores all lifecycle phases’ data. The function is mainly manifested in storage, Data Synchronization, data security control and data record transactions. The content is made of structured and unstructured repository, where the DMIM contains core data. Typically, the structured data adopts bottom database to store and manage, such as Oracle, SQL Server, Sybase and other large database. The unstructured data adopts file data base to storage and management. The layer stores the original information of the framework to provide data support for the layers above. It is necessary to propose a channel to seamless integrate data modeling layer and core application layer to solve the problem that data format does not correspond to application. The way of adopting Project Model Proxy Services, (PMPs) and middle ware may compensate for this gap.

To integrate MLM system, this paper adopts: 1) Document Management Server and Relationship Database Management System (RDBMS) to manage data; 2) model servers to process specific information; 3) middle ware to integrate distributed and heterogeneous multi-applications; 4) PIP to realize distributed collaborative work; and 5) a unified information classification and coding system. All the above are the important components to realize the MLM system integration.

![Architecture of MLM implementation system](image)

A number of issues have to be investigated before implementation of a MLM system support and interoperability platform based on the proposed mining information-modeling framework at the beginning. It is necessary to discuss the critical success factors (CSFs) of MLM integration.

Firstly, the framework presented is but a first step towards a complete mining modeling architecture supporting the MLM concept. A search needs to be done to identify other framework components that need to be modeled and integrated.

Secondly, a focused search of the MLM literature and current MLM system products needs to be made so as to clarify all mining information needs throughout the MLM process to develop a conceptual Application Programming Interface (API) that can serve all mining information to all MLM process components. As part of such a conceptual interface specification, considerable attention needs to be given to the possible interactions between the mining data served by the framework and Meta data about the mining data maintained by the MLM system.

Thirdly, the key of the mining integration is to develop information and data standardization system. It is not only related to the sharing of basic information platform, but also related to the exploration and evaluation of mineral resources. The lifecycle of mining process is linked to many types of software, such as GIS, CAD, Surpac, and Micro mine software. The software provided by different vendors has different data models and data standards. The computer programs for data mine design,
analysis and maintenance could usually not exchange data directly, even when the same team used them. Mines took a longer time to be designed and exploited. Information sharing should be regarded as the starting point when using information technology to architectural design, construction and production. Information sharing requires a software environment in which computer programs can exchange data automatically regardless of software and data location. To get this goal, the National Mineral Information Standards Committee (NMISC) proposed a series of standards that specifies object representations for mining projects. The standards, involve network platform structured standard, basic data information standard, and drawing standard, in which could imply terminology, code and schematic illustration standardization.

Fourthly, integral and consistent information model definition covers various mining life cycle phases. To ease collaborative design and production in contemporary enterprises, it is important to create a multi-dimensional mine information model composed of related 3D virtual models, workflow processes, producing resources, tools, etc. Mining lifecycle management need establish a global multi-dimensional-view mine model to realize the consistent and integral description and management of product information.

Finally, service-oriented is discussed. Mining content is distributed in various places, to implement management and collaboration in intranet and internet, we can adopt service-oriented theory and technique to guarantee sharing and optimization of contents more effectively.

IV. CASE STUDY

Based on the above concept and architecture of MLM implementation system, a MLM application case is taken in mining building sub-modeling system throughout the building’s lifecycle. 3D MLM is collaboratively built, referenced and enriched. The whole process is divided into four phases. The first one focuses on preparing production schedule. In the second phase, 3D building models are designed. The third phase is about data exchanging for all the other actors of the restoration project. The last phase provides the platform for engineers to add/extract/validate design data.

Firstly, after requirement analysis, the project manager uses Autodesk Navisworks software to plan all the lifecycle and their tasks to develop the building.

Secondly, designers receive their design task and use Autodesk Revit software to design the building of architecture, structure and MEP aspect. When designers finish their tasks the 3D model and the prototype system view is formed. The building model is available for all the other actors of the building restoration project.

Thirdly, all the other actors of the project participants can exchange building information data. Persons receive their tasks for evaluation and use the test tools to test whether or not the above designed product meet the requirement. The 3D models exported from Revit software are imported in Autodesk Navisworks software platform to test crash detective and run 4D simulation of construction process as shown in Fig. 10, Fig. 11. If the designed building does not meet the need of the mechanical designers, software designers must work together to modify their design until the building is right.

Finally, persons of manufacturing receive their tasks and construct the building. Moreover, the lifecycle is formed gradually as the building is developed. In terms of PIP (project information portal), the information between the group of project participants and server is more efficient than before. The PIP can realize project communication and collaboration online for all team actors. Once the information model has been placed, other actors of the project connect themselves to the PIP platform and retrieve this information and to enrich the 3D models. The engineers can add/extract/validate design data in the PIP platform. The tasks are arranged as the organization view shown in Fig. 12.

From the above introduction of a mining building development lifecycle, it is obvious that a MLM is very helpful to every person in the lifecycle process because MLM realizes the information sharing among the group members, which makes the distributed nodes’ jobs be accomplished smoothly and collaboratively.

V. CONCLUSION

This paper makes a proposal for a single MLM system support framework for mining life cycle information management.
1) The concept of MLM is proposed, based on product lifecycle management (PLM) and Hall three dimension structures, the conception of mining lifecycle management (MLM) is proposed. MLM (mining lifecycle management) modeling supports interchanging and sharing mining content of different phases and different fields. The content includes geometry, virtual structure, virtual behavior and process information which run through mining lifecycle from requirement analysis, design, and production, operation and maintenance. 2) The methods to build 3D view MLM are put forward, including virtual prototype system view, organization view and time view. The virtual prototype system of integration is achieved in terms of DMIM models. The new project delivery models and Collaborative work, the organizational integration is obtained in interface management. The time integration is given in constructing integrated process model. 3) The four-layer structure realization of MLM system is put forward; the development method of MLM system is put forward according to the structure.

The application indicates that the proposed theories and technologies solved the problem of information isolation in different phases and application in mining engineering, and laid a foundation for information exchange, sharing and integration in mining lifecycle.

ACKNOWLEDGMENT

The authors wish to express their appreciation and thanks to Professor Caiwu Lu and Zhen Yang, for their valuable suggestions and discussions on the topic of this paper.

REFERENCES


Na Lu (1981- ) is a Ph.D student of Xi’an University of Architecture and Technology of China. She received her master degree in Management System Engineering from the Xi’an Technological University of China. Her research deals with information systems, computer-aided engineering, multi-scale modeling and simulation, and engineering databases.