

An-lin Shao

# Digital Mine Research and Practice Based on Mining and Metallurgy System Engineering

**Abstract** Iron ore is necessarily basic raw material for industrialization and urbanization and related to the industrial distribution and development programming. The lean iron ore resource in our country is high-cost and low-efficiency, which cannot meet the demand of iron and steel industry, and even endanger the safety of industrial economy. Ansteel mining has created “grade decision-based multi-system integration” mode of mining and metallurgy system engineering and realized scale and efficient development of lean iron ore on basis of the construction of digital mines. Moreover, the “wisdom mines” was proposed and had led to the transformation and upgrading of iron developments.

**Keywords:** exploration of lean iron ore, mining and metallurgy system engineering, digital mine, wisdom mine

## 1 Introduction

The quality and quantity of iron production in China has improved a lot with the rapid increase of economy in China since its reform and opening up. China has become the largest steel producer in the world. The crude steel production, which was 0.8227 billion tons in China in 2014, has reached 49.5% of the global crude steel production (1.662 billion tons) according to statistics released by the International Iron and Steel Institute, and became the largest steel maker in the world.

The proven reserve of iron ore resources in China is approximate 75.6 billion tons, which is the fourth in the world. However, 99% of the resources are lean iron ores, which need purification processing before smelting. On the contrary, foreign mines mainly compose rich mines. Because of the low development of lean iron ores in China, the import dependence is more than 70% and the import volume has accounted for more than 60% of the total international trade volume. Thus, the price of iron ore

is always controlled by the foreign mining giants. The international price of Department of Construction Management, University of Houston, Houston, Texas 77204, USA.

Iron mine has been improved 6 times from 2003 to 2013, which induced more than 2 thousand billion CNY paid by the domestic steel industry. In 2013, the total profit of the three mining giants abroad was 18.6 billion CNY. It is really a pity that China works for the foreign mining companies even though she owns the largest iron and steel industry in the world (Cui, Xia, & Wang, 2012).

The heavy dependence on imported ore, which is a hold on the iron industry in China, not only decreases the small profits, but also influences the safety of iron as the primary industry of the national economy (Wilson, 2012). Thus, it is essential to improve the lower grade domestic ores and make an overall plan of iron resource in both home and abroad. It is also a strategic choice for the guarantee of the national economy and national security.

## 2 Three challenges of development of lean iron ore

The global iron resource, whose amount is about 800 billion tons, is very rich. However, the southern irons, which mainly distribute in Australia, Brazil, etc., are richer than those in northern area (Yellishetty & Mudd, 2014). China is mainly composed of lean iron ores and has to face three principal challenges during the exploitation and utilization.

First, the characteristics of iron ore in China are poor, thin, complex and scattered. The average grade of iron ore is only 30%, which is 30% lower than the rich iron ore abroad. Meanwhile, the grain size is small and the crushed grain size should be smaller than 50  $\mu\text{m}$  to efficiently purify iron. The associated elements are also difficult to separate. What's more, the ore body is usually distributed in banded structures and the largest depth can be more than thousand meters (Li, H., Li, L., & Yang, 2015; Li et al., 2014). It brings heavy pressure to develop the lean ore mines in our country, and the process and purification is also a worldwide challenge.

Second, the engineering system is complex and the scale

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An-lin Shao (✉)

Ansteel Mining Group, Anshan 114001, China  
Email: alshao@163.com

and efficient development is difficult. Anshan mining group is a huge group whose business contains exploration, mining, ore blending, mineral processing and smelting. The five processes are consisted in an open complex giant system which is used by the process industry and discrete industry. So the technology and management are faced with great difficulty.

Third, the influence on environment cannot be ignored and the green development is urgently needed. The exploitation of the lean iron ore resources occupied the land, damaged the surface, emitted large amounts of waste such as rock, tailings, waste water and gas, and caused the geological hazards such as landslide, debris flow and subsidy, which can be damage to the ecological environment (Wu, Jiang, Chen, Tian, & Xu, 2009; Verma, Chaudhari, & Satyanarayanan, 2012).

### **3 Digital mining construction of the mining and metallurgy system engineering based on the “grade decision-based multi-system integration” mode**

There are contradictory elements in the mining and metallurgical engineering as the result of the managerial thinking limitation, which is mainly true with three aspects. The first is the thinking of local optimization. It means inappropriate handling of the relation between parts and the whole, which often highlights the optimum of the index system and the benefit maximum in the particular section and ignores the profit and outcome of the total system. In the process of surveying, selecting and smelting, every systems are optimized separately, and therefore each single system comes to the best system index but the total system does not. The second is the linear thinking. It means inappropriate handling of the relation between quality and efficiency, technology and engineering. In the pursuit of mere technology and “fine goods”, the integrated functions of engineering management are ignored and the quality standard is overestimated. And the metal recovery rate decreases and the cost of metal increases. Although the technology is promoted, production capability cannot be established. The third is the utilitarianism. It means inappropriate handling of the relation between the economy benefit and the society benefit. It emphasizes interests excessively and ignores resources recycling and environmental pollution, which leads to high geological grade and concentrate grade, low rate of recycling, and large emission of waste rock and tailings discharge.

#### **3.1 “Grade decision-based multi-system integration” engineering mode of the mining and metallurgy system**

Ansteel, as “the republic eldest son of the industry”, constructed the factories according to the location of iron ore resources which is the most all over the country, and

had the representativeness of the resources characteristic and utilization level. From the sixth “Five-Year Plan,” the metallurgical ministry organized to tackle key technical problems on the lean iron ore development, but it failed. In the past 15 years, Ansteel mining summarized the experience and lessons in the guidance of engineering philosophy. We dialectically consider the practical mine development, discover the nature of mining process, grasp the whole of in terms of the philosophy of engineering system, value, safety, ecology. These refer to theoretical results of analysis-integration method of production process, make a breakthrough and establish a management mode and coordination production of five processes which is also called “grade decision-based multi-system integration” mode.

The mode put forwarded “mining and metallurgy system engineering” concept at first, broke through independent process of the mining and metallurgy. Set the node parameters based on the corresponded iron content indicators of the five processes including cutoff, milling, concentrate and furnace grades. Built network ganged connection between working procedure, mines and factors to make system under the self-organized state of dynamic optimization, break through the technology and management problems, and come true system optimization and value maximization.

The major ways: the first is to integrate five processes into the one, turn single-mine exploitation to multi-mines combined exploitation, change linear and disperse layout to network and intensive layout and eventually come true the best “grade decision-based multi-system integration” allocation according to the entire engineering structure. The second is to change the single grade to the “grade decision-based multi-system integration” project and come true the global technical optimization through the key technical breakthroughs and optimization according to integrated and reshaped technology series. The third is to construct “grade-profit analyzed decision-making platform”, implement dynamic optimization of the multiple targets including quality, cost and scale, turn independent operation to five grades ganged operation. Eventually comes true the maximum system efficiency according to the collaborative and reconstructed management system. The nature is the revolution of the mining and metallurgy engineering and management system (Shao, 2013a, 2013b).

#### **3.2 The practice and study of the digital mining construction**

Anteel mining put forwarded digital mining ways to support “grade decision-based multi-system integration” mode, integrated the new information technology including things, cloud computing and big data into the practice of the mining metallurgical engineering, and came true the inter-drive and high-effective combination between virtual mines and entity.

### 3.2.1 Digital labor factors

Resources exploitation is to study an unknown world because of its uncertainty, and every process needs quick responses according to the mining and excavation results. Ansteel mining has digitalized labor objects, tools and personals to lay a foundation to the digital construction.

A. Labor object digitization. Ansteel mining used the advanced and dynamic data acquisition methods including laser scanning, UAV, thermal imagery and measurement robots, displayed mines and ore bodies comprehensively through building high precision and panoramic 3D digital platform, built the world-leading geological information system. The system has 142 features including production and exploration, reserve calculation, measurement acceptance, analytic statistics of the quantities, mine development design, production technique and construction design, mining engineering design and preparation of the production plan, came true virtual simulation of the production status. Ansteel mining realized digital mining and excavation goals and improved resources utilization efficiency through the construction of synthetic geology information system.

B. Labor tools digitization. Aim to the dispersion equipment in the mines, severe working environment and the difficulties of the integration control, it used accurate differential positioning device. Mesh mobile networks and 3D scanning technology methods, built the whole-process intelligent controlled system and came true equipment interconnection, centimeter level positioning, real-time state monitoring and remote control. Otherwise, methods like mathematical modeling and visual monitoring can make the comprehensive perception to the equipment and dynamic real-time monitoring, and moreover improved the overall efficiency.

C. Labors digitization. Ansteel mining constructed the management and control integration system to identification, personnel location, special emergency avoidance, liaison, and mobile working, improved the labors power of the collaboration, quick responding and safety precautions. It also constructed mobile office system, realistic work system, process publishing platform and mobile application platform, managed the labors' office information digitally, and improved the efficiency and regulated working behaviors. Additionally, constructed the many platforms including knowledge management, employee training and technical support. It came true "implicit knowledge explication, explicit knowledge implicitization and structural knowledge digitization."

### 3.2.2 Integration of process management and control

Mining and Metallurgical Engineering is an integrated activity which carried out in an organized manner extracting the minerals, and also open, non-deterministic, dynamic, complex systems far from equilibrium. So the

integration of process management and control is a major problem which perplexes the industry. Ansteel mining group formed the integration solutions through researching the system of development control, of manufacturing execution, of enterprise resource planning.

A. Process control system. In basic automation level, we insist on the policy of the combination of monomer process automatic control and automatic control system, break through the single loop, closed loop control and other traditional control problems by using the advanced technology. The Ansteel mining group develops the self-diagnosis and self-correction and maximizing the function program, mainly builds crushing expert system, balls mill expert system, sintering expert system and pelletizing expert system, implements integration automatic control system. On this basis, we established a unified real-time database by the acquisition of data on a unified platform, unified timing, and unified structure. It implements transparent management, stable operation, and system linkage through the whole process of tracking and control.

B. Manufacturing execution system. In the production management level, Anshan mining establish unified execution control platform (MES) including production management, production of realism, quality management, metering management, equipment check, planning, maintenance, spare parts management, energy control, video monitoring, device simulation function module, etc. Through the construction of efficient and stable data bus system, we comprehensive configure from two dimensions of process and function, standardization integrate of different business function module data, promote the automatic control system and the effective connection between enterprise resource plannings. The platform covers the production task planning decomposition, production status real-time monitoring, and dynamic adjustment of the whole process of the production order, just-in-time production organization operation, visual display and intelligent service.

C. Enterprise resources planning system. In the enterprise management levels, we implement the integration of enterprise resources, process reengineering and dynamic optimal allocation around cost, finance, purchasing, manufacturing, equipment, engineering, quality, sales, human resources, production safety, supplier management, and other various modules. We complete the ERP system, eliminate enterprise information isolated island and realize the "information, cash-flow, capital" third-rate unity. Efficient, standard, synergy goals are met. On this basis, promoting enterprise financial accounting by the secondary to the primary accounting change, the implementation of financial centralized control and establishment of a "financial sharing center", refine the cost management, strengthen the overall control, and improve the efficiency of management. ERP system achieves the goal with financial management as the core, with the pursuit of the maximum benefits of enterprise on the premise of

production safety, environmental protection, resource utilization and other requirements.

### 3.2.3 Analysis and decision intelligence

Technological process and metallurgical engineering are complex. Many problems during the engineering activities are also complex and interactive. Traditional management methods are difficult to make a scientific analysis and good decision. But application of the information methods to analyze and process massive datas can contribute to make optimum decision and maximize the interests at least cost.

A. Wisdom analysis model. The five processes of the lean iron ore development corresponding to the iron content of iron ore development indicates that geological grade, production grade, milling grade, concentrate grade and in-furnace good are key decision parameters. An index change will cause a chain reaction of the whole system. With five parameters for the node, the establishment of the grade-cost analysis model, grade-benefit analysis model, grade-environment analysis model constructed network correlation between processes, mining and elements. It can provide the real-time analysis and optimize adjustment for quality, cost, efficiency and environment. Moreover, it can provide optimal decisions for making the mining engineering activity (Shao, 2013; Shao & Yin, 2014).

① The total benefit  $T$  is the largest target and a grade-benefit analysis model is established by Eq. (1).

$$T = \frac{Q_1(p_1 - \alpha_C)(1 - q)}{p_2 - \alpha_C} \left\{ \frac{p_2 - \alpha_Y}{p_3 - \alpha_Y} \times \frac{p_3 - \alpha_X}{p_4 - \alpha_X} \right. \\ \times \left[ X_Z \left( \frac{p_4}{p_{5Z}} C_5 - C_4 \right) + X_S \left( \frac{p_4}{p_{5S}} C'_5 - C'_4 \right) + X_J C''_5 \right] \\ \left. - \left[ (C_1 + C_2) + \frac{(p_2 - \alpha_Y)C_3}{p_3 - \alpha_Y} \right] \right\} \quad (1)$$

where  $p_1 \sim p_5$  is the each link for the corresponding grade;  $Q_1$  is the delineation of ore;  $q$  is the loss ratio of ore;  $X_Z$  is for the pelletizing ore accounted for percent of concentrate;  $X_S$  is for the sinter ore accounted for percent of concentrate;  $X_J$  is for sold directly to concentrate powder accounted for percent of the production concentrate;  $C_1, C_2, C_3$  and  $C_4$  are respectively the link unit cost;  $C_5$  is the pellet of sell price;  $C'_5$  is the sinter of sell price;  $C''_5$  is the concentrate of sell price;  $\alpha_C$  is the grade of mixed with gangue;  $\alpha_Y$  is the grade of pre-selection process of removing the ore;  $\alpha_X$  is the tailings grade,  $p_{5Z}$  is the pellets grade,  $p_{5S}$  is the sintering grade.

② The minimum of the total cost  $F$  is the goal and could be presented in the form of Eq. (2).

$$MinC = \sum_{i=1}^4 t_i f_i(p_i, p_{i-1}) \quad (2)$$

where  $t_i$  is each link of production;  $f_i(p_i, p_{i+1})$  is each segment corresponding cost,  $p_i$  is each link of the grade.

③ To impact on the environment  $E$  minimum for target, a grade-environment analysis model by Eq. (3) is established.

$$E = \frac{k_1 \alpha (p_3 - \delta_2)(p_4 - \delta_3) \left( Y - A e^{-\frac{p_2}{B}} \right)}{(p_2 - \delta_2)(p_3 - \delta_3)(p_4 - \delta_4) \left( Y + A e^{-\frac{p_2}{B}} \right)} \\ + \frac{k_2 \alpha (p_3 - p_2)(p_4 - \delta_3)}{(p_2 - \delta_2)(p_3 - \delta_3)(p_4 - \delta_4)} \\ + \frac{k_3 \alpha (p_4 - p_3)}{(p_3 - \delta_3)(p_4 - \delta_4)} \quad (3)$$

where  $p_1 \sim p_5$  is the each link for the corresponding grade;  $\alpha$  is the grade factor;  $\delta_2$  the tailing grade of preconcentration processing;  $\delta_3$  is the tailing grade of grade mineral processing;  $k_1, k_2, k_3$  are the environmental impact factors of mining, pre-selection, mineral processing, respectively;  $\delta_4$  is the Iron dissipation factor on smelting stage.

B. Intelligent decision-making system. The key of the system is to summary the various information in the mining and metallurgical engineering activities, and organic. Combine the method of systems analysis, operations research and the of computer technology. Then construct the integration of smart, exchange, and integrated decision support system with the production statistics, management, financial analysis, form “cockpits” for managers at all levels. The system on the one hand focus on the problems found, the analysis of the reasons, provide data support for rapid response to the problem of production and management decision-making and coordinated management and departments. On the other hand, provide the problem analysis, simulate decision-making of program suggestions and running environment, can call a variety of information resources and analysis tools, to help decision makers to improve the decision-making level and quality. Intelligent decision-making system change the results control to process control to make the mining engineering activity always in a state of dynamic optimization of self-organization, and get the biggest value to achieve optimum system.

The Ansteel mining company constructed Ansteel Mining Management System (AMS) including labor factor, resource allocation and transportation decision. It built a large ten-gigabit enterprise network including management, control, MES, video conference and video monitoring as a whole, put various factors into a network platform. This covered the whole life cycle of the mining and metallurgical engineering including research, design, construction, and operation, and finally came true the “whole dynamic and controllable process, precise and coordinative process, optimal performance and the maximum global benefit” (Li, 2012). For details, see Figure 1.

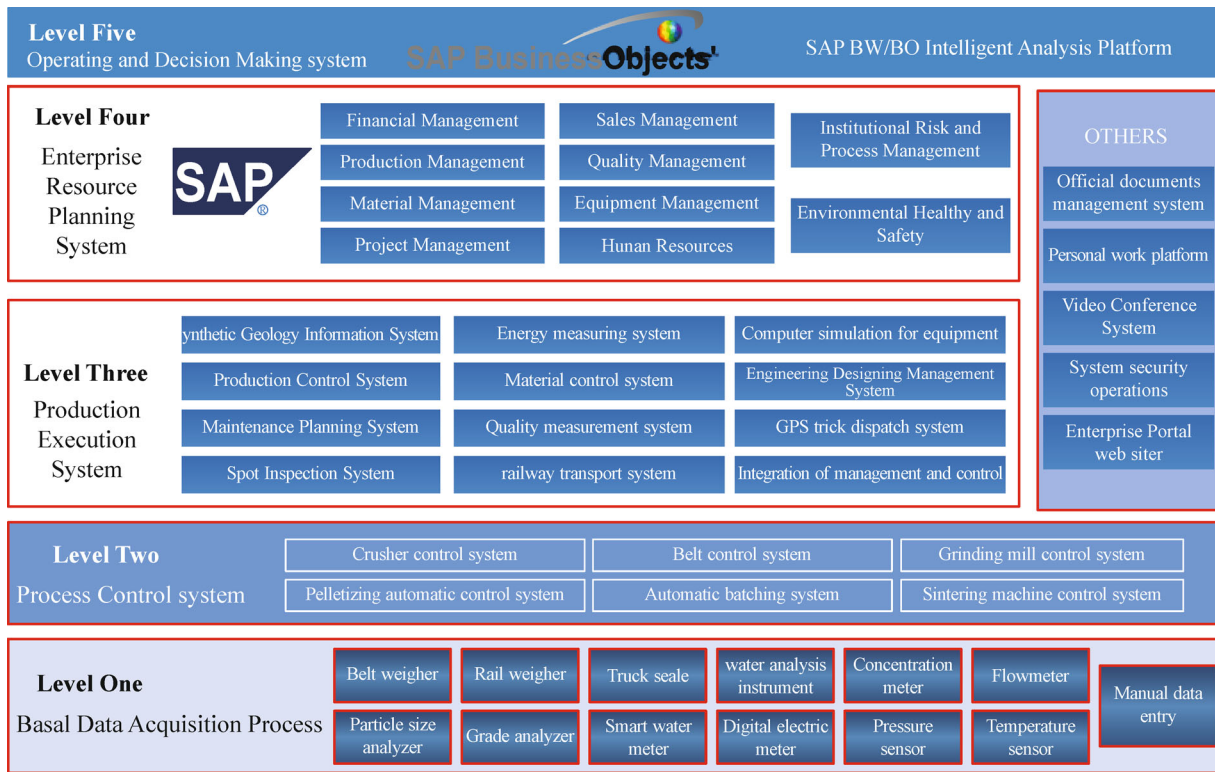


Figure 1. Site structure of the AMS.

## 4 Research and outlook of the wisdom mine

On the basis of the digital mining construction, Ansteel mining combined the German industrial 4.0 with development strategy of “Made in China 2025”, moreover proposed the development goal of “Wisdom mine”, drove the mining industries to change through the deeply integration of industrialization and informatization.

### 4.1 German industry 4.0 and made in China 2025

Germany proposed the concept of industry 4.0 to face the development trend of combination between the new generation information technology and the manufacturing. Its purpose is for consumers highly personalized needs, providing rapid response solutions (Ding & Li, 2014; Kotarski, 2014; Feld, Hoffmann, & Schmidt, 2012). Our government proposed the development strategy of “Made in China 2025” (He & Pan, 2015). It makes “The Internet +” as a whole framework, and insists on the ideas thread of “deeply combination between information and industrialization”. It follows the construction ideas of “business + data”, and takes the “driven by innovation, quality first, green development and structure optimization” as the key.

The domestic mining enterprises must follow the direction of “German Industry 4.0” and “Made in China 2025” after digital construction practice. The change from digital to wisdom is to increase the content of “wisdom

management” on the basis of wisdom factory and production. The key is to excavate and manage the massive information globally, effectively and orderly and represent the wisdom demand during the whole dynamic equilibrium and harmonious development in the mining and metallurgical engineering.

### 4.2 Wisdom mines research direction

Wisdom mines made safety production, ore resource estimation, mine design, excavation design and decision management active sensing, automatic analysis and quick decision through the technology of modern space analysis, data mining, knowledge mining, virtual reality, visualization, network, multi-medium and scientific calculation. Compared with automatic and digital mines, wisdom mines have better perception, more comprehensive connectivity, a better understanding of intelligent features. Wisdom mine will bring greatly improvement for mining enterprise in innovation capability, production save capacity, resource utilization, enterprise management and control capacity, sustainability, cultural literacy and so on (as shown in Figure 2), which has far-reaching significance on enhancing core competence of the enterprise, promote the industry advance and secure the national economy and industry.

In the future, the construction of the wisdom mines is to make the following researches:

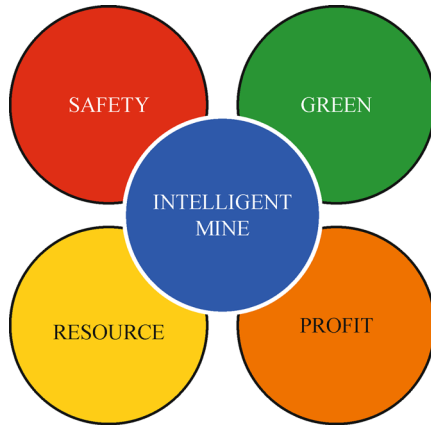


Figure 2. The ultimate goals of Wisdom mines.

#### 4.2.1 Deep integration research of the mining production

Using reliable network environment, we implement the overall solution of the unmanned mining operation. Unmanned mining production is not only for safety production, but also be an inevitable choice to improve labor production rate and reduce the cost in mining enterprises. Based on the full implementation of the existing mature technology, we conduct research work on the model of human or unmanned control in different parts of production process.

#### 4.2.2 The research of big data analysis and technology application

It is significant to conduct research work on the digital model of transformation from production status data into process information, and then implement data analysis and integration to achieve the “Real-time Factory” of data value management and data visualization. It is necessary to establish production process information knowledge base and realize knowledge management. It is important to establish mine production process model base and knowledge base that can meet many kinds of application, form the whole process distribution, multi-level hierarchical intelligent management control and decision support application service system. It is critical to carry out data analysis standardization research, establish the data exchange system and the data fusion technology in the ore production link, and form the industry management platform.

#### 4.2.3 The research of information service model

Based on feasibility of cloud services in mine application system, we set up industry information service platform to achieve information of hardware and software resources of cloud services. Relying on the advantage of brand, we

conduct research work on the transformation of enterprise electronic commerce platform to the industry public platform, reflect objectively the quality of external supplier service and provide support to improve the whole industry supply chain management level. We also carry out the research on the construction of the mining industry information standard system, and form a standard system management mode which has distinct mining characteristic, real time publishing management and version control function. This is in order to realize the dynamic update of the relevant standards of enterprise management, and wisdom retrieval.

Construction of wisdom mine is the product of high speed development of information technology. The domestic iron ore mines should build systematic engineering thinking, fulfill the “Internet +” concept, make use of the modern information technology, push the development of the industrial restructuring, and explore the information development path of the mines characteristic.

In brief, as poor iron ore development is of great significance to Chinese industrial safety, it is necessary to establish the concept of engineering philosophy, deepen the research and application of “grade decision-based multi-system integration” mining systems engineering model, create comprehensive digital mines, actively explore the wisdom mines. All of the above plays an important role to achieve the goal that lean iron ore is mined out in low cost and green and efficient development, which can promote core competitiveness of domestic iron mining enterprises, and create a healthy and sustainable development of the iron ore industry.

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