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ENGINEERING MANAGEMENT TREATISES

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Integrated Optimization and Management of Mining Engineering—Coordinative Operation and Optimal Management of Five processes in Mining Engineering

Abstract In the view of engineering philosophy, the mining engineering is a dynamic operating process of ferrous material flow, in which the ferrous material flow is processed orderly through a series of continual coordinated procedures. It is also a process of discarding the dross, selecting the essential, and extracting the original metal. The object of management is to fulfill the multi-objective optimization. The proportion of lean ores in iron ore resources is 82% in the world and even 97% in China but their utilization is very low. Aiming at the bottleneck and weakness of China's resource development, this paper analyzes and plans the mining engineering system as a whole based on the ideas and methods of system theory and engineering philosophical thinking. And the paper proposes the "grade decision-based multi-system integration" engineering management mode, which considers the relationship between engineering and environment and complies with the natural law. In the mode, the mining engineering, including geologic mining, ore blending, concentration and pelleting, can be viewed as a whole and the geological grade, mined ore grade, feed grade, concentrate grade and feed grade of blast furnace can be considered comprehensively. The mode reflected the overall structural optimization idea, realized the analysis, coordination and optimization among the multiple functions and processes, and thus drove the overall efficient and profit optimization throughout the processing flow. The establishment and the application of the "grade decision-based multi-system integration" mode have solved the lean iron ores exploitation problem and supported the "self-sufficiency" resource strategy.

Keywords: engineering philosophy, multi-system integration, engineering management, objective optimization, lean ores exploitation, mode

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1 Introduction

The engineering philosophy is a subject respected to the fundamental viewpoint and general law in engineering activities. As a prospective engineering idea at home and abroad, it focuses on the research and analysis on the engineering decision and strategic problems (Yin, 2007). In the dialectical relationship between practice and knowledge, the former is the base of the latter and has a decisive effect on the latter while the latter has a reaction on the former. Therefore, it has great promoting effect on the practice to realize the nature of mining engineering properly and rationally. There exist two contradictions in the exploitation and utilization of iron ore resources in the world, which result in the general deficit throughout the domestic steel industry and pose a great threat to economic security of China.

The first contradiction lies between industrial scale and resources. China is the largest steel-making country in the world, whose crude steel production is nearly half of that of the world. However, subject to the domestic iron ore resources, we depend on the imported rich ores. The second contradiction is between value contribution and benefit distribution. The profit of Vale of Brazil, Rio Tinto and BHP Billiton is up to $17.3 billion in 2012, but the profit of top 77 companies in China is only $0.25 million. The domestic iron and steel industry is actually in deficit if excluding the non-steel business profit. The steel-making creates great values but owns small profits in a long industrial chain while the mining holds nearly all the profits but creates low additional value with a short industrial chain.

In fact, China, as a big iron ore resource country in the world, is not lack of iron deposits but 97% of those resources are lean ores. These resources have not been utilized efficiently, although a lot of researches have been made on the problem and some of the technological shortcomings have been overcome. It is discovered that the engineering management bottleneck limits the resource development and utilization. And we have not given enough attention to the engineering management, which results in the deficit situation of the mining engineering and hinder our economic development.

There are contradictory elements in the mining engineering as the result of the managerial thinking limitation, which is mainly true in three aspects. The first is the thinking of local optimization. It means inappropriate handling of the relation between the 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 pelleting, all 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 economic benefit and the social benefit. It emphasizes interests excessively and ignores resource 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.

The engineering is based on the technology and succeeded on the management. 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, refer to theoretical results of analysis-integration method of production process (Yin, 2009), 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, a kind of Mining Engineering mode. Under the mode, the exploitation of lean iron ores, which had been a worldwide difficult problem, was resolved. It made billions of tons of ore minable. Ansteel Mining fulfilled the self-sufficiency resource strategy through enhancing the mine scale and building a world-class iron ore mine. It has a great significance for increasing the proportion of self-sufficiency ores and controlling the price of imported iron ore (Shao, 2012; Zhang, 2007).

2 Research on "grade decision-based multi-system integration" engineering management mode

2.1 Origin of "grade decision-based multi-system integration" engineering management mode

In the perspectives of engineering philosophy, every engineering activity is undertaken on the basis of a certain engineering theory. Different engineering theories exert influence on each stage and section (Yin, 2007) actually. Mining engineering is an integral activity, including geological engineering, proportioning engineering, mineral processing engineering and other sub-domains. From the view of engineering philosophy, the ferrous material flow is processed orderly through a series of continual coordinated procedures, and a process of discarding the dross and selecting the essential, extracting the original metal. The target of management is to achieve the multi-objective optimization such as high productivity, good economic benefits, low cost, high quality, low power and friendly environment, etc. Therefore, each step of mineral engineering interacts intimately and has an effect on the entire engineering project due to their grade-based relations. How to realize the global optimization of all processes, to a maximum extent, is a key point of research of mining engineering. Based on the root of mining engineering, the breakthrough constitutes the key point in the problem-solving of mineral engineering's contradictory. It demands overall systematic thinking, views of ecological ethics, harmonious engineering, understanding of the law of mining engineering and then realizing of the global process optimization. "Grade decision-based multi-system integration" engineering mode comes into being under the law of engineering development, to realize the integration of engineering and technology, time and space, the parts and the whole, and the economy and the society.

2.2 The meaning of "grade decision-based multi-system integration"

Ansteel Mining has built the "grade decision-based multi-system integration" mode based on the nature of mining engineering, which takes the engineering philosophy, system theory, marginal utility theory as the theoretic instruments, and takes the large complex mine construction project as practical background. The mode integrates the exploration, mining, ore blending, processing and pelleting sectors together to one optimization and simultaneously determines five grades: geological grade, mined ore grade, feed grade, concentrate grade and feed grade of blast furnace (referred to as "five grades" hereafter), corresponding to the former five sectors, respectively. Also it analyzes and coordinates the whole engineering system based on philosophical thinking, takes the resource protection of ecological environment into consideration in the process of engineering design and construction, reduces the emission of pollutants, reaches the state of "will-better", and eventually achieves the goal of harmonizing with ecology and society.

The "grade decision-based multi-system integration" engineering mode is the whole optimization of global processes. In other words it means the analysis-optimization of process capability integration, coordination-optimization between the relationship of process and restructure-optimization in the process. The structure optimization promoted efficiency and benefit of the whole operation, which involved in design concept, method creation, guidance creation of mine production, marketing strategy creation, design and construction program creation.

As illustrated in *Figure 1*, five subprojects are connected with each other by dynamic optimization system. In a solid line of clockwise direction, grade enrichment and quality of production increases gradually, which is a process of resource enrichment. Previous engineering has a direct effect on the craft, scale, cost, quality and environment of the following engineering. Along a counterclockwise direction of dashed line is feedback, tracing causes and previous engineering organization and technological tackling of dynamic optimization.

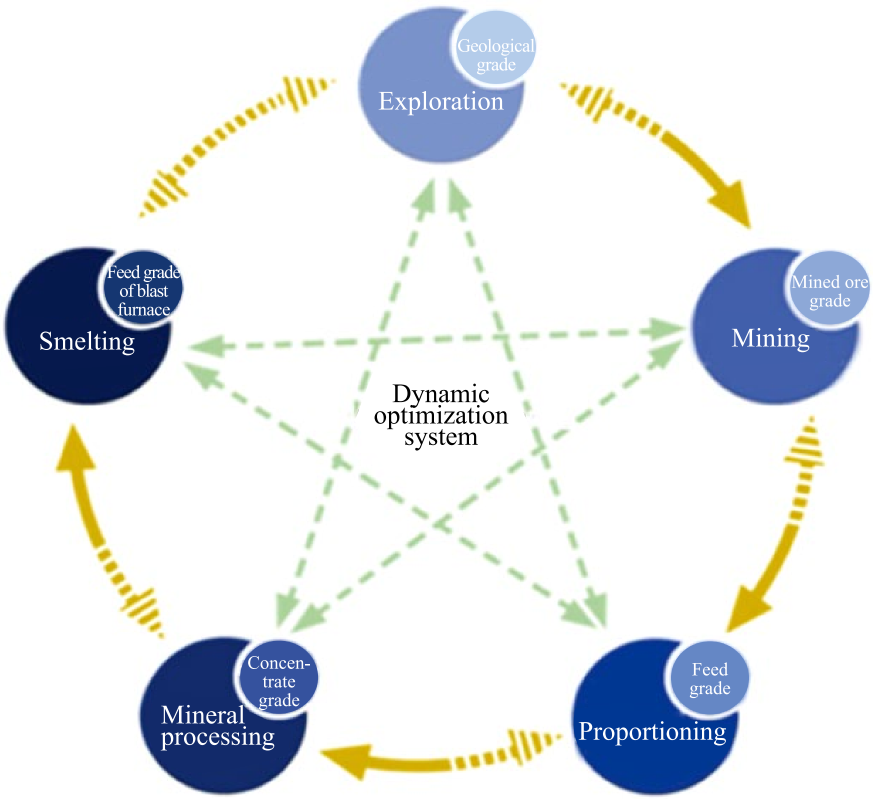

Figure 1. Illustration of the "grade decision-based multi-system integration" mode.

It is incomplete to analyze every single grade alone because the variation of any one of them can affect the entire production system. During the process of production and management, every step has its disadvantage. Thus, focus should be made to solve them by the technological innovation creation. In the process of solving the problems, the system integration can make five grades increase spirally.

2.3 Mathematical model research of "grade decision-based multi-system integration" mode optimization

According to the quantitative description of the relationship among grade, profit, cost and environment of the sub-systems, we consider multiple targets such as production, cost and profit as decision variables and formulate mathematical model. Taking advantage of non-linear optimization technology, a solution to the model could be made (Li, 1997; Haken, 1984; Hermann & Paul, 2012; Wang, 1998).

Grade-decision involves the whole mining engineering including prospecting, mining, and BF iron-making (*Figure 2*). Target optimization can minimize production cost of unit liquid iron, namely minimizing the total mining cost. Under some geological grade circumstances, the cut-off grade decides the reserves of the mine. The use of different cut-off grades can affect mined ore's average grade and unit mining cost when mining. Various mined ore grades can affect ore blending. Under the fixed processing technology, grade of crude ore and concentrate grade has a direct effect on the cost of processing. Within certain limits to improve concentrate grade, ingredient and energy consumption of iron-making were reduced.

From the relationship between many production stages and grades of mining process we can see that the grade of previous process is the material grade of the next one for adjacent process. This grade can connect the two processes. We need to cut down the cost of the followed process to upgrade while increasing the cost of the previous. To optimize every

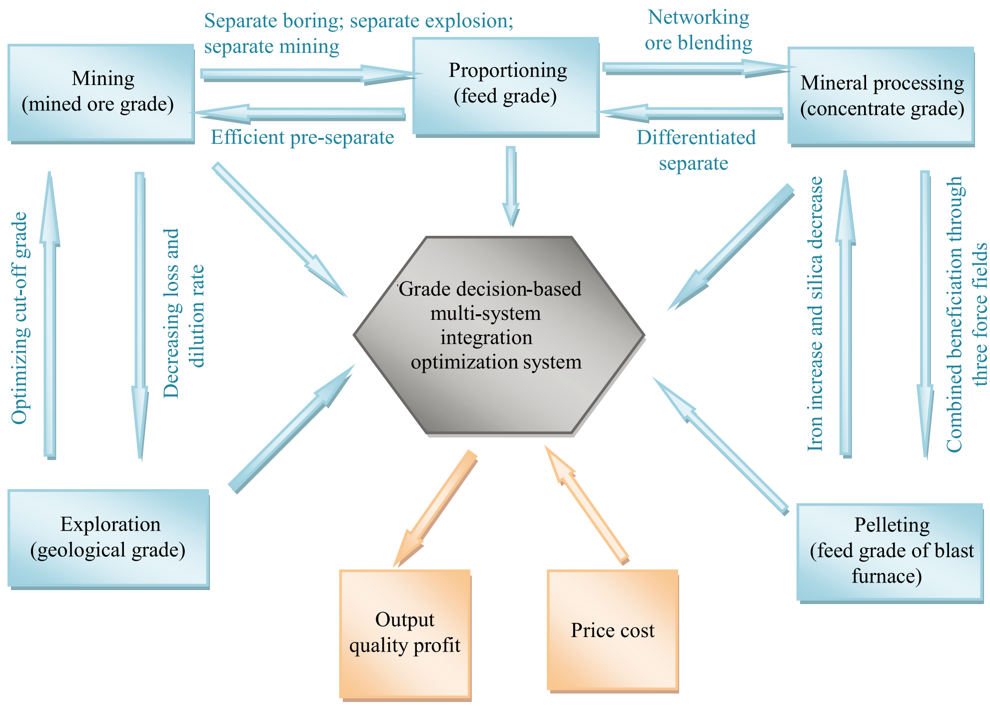

Figure 2. Schematic diagram of relationships between mining engineering.

adjacent-process grade, the production cost of adjacent process need to be considered comprehensively, so as to achieve a balance. Because of the interaction of linking-grade among every production process, a single grade will have an effect on the best grade variation of multiple processes.

Therefore, the model of grade cost of every production process can be established by analyzing the influence of different linking grades on related production process based on marginal cost theory of economics (Ataei & Osanloo, 2003; Liu, 2012; Robert & Takayoshi, 2003; Shu & Chen, 1995; Takayoshi & Takashi, 2000).

The total benefit B is the largest target and a grade-benefit analysis model is established by Equation (1).

$$B=\frac{Q_1(p_1-\alpha_C)(1-q)}{p_2-\alpha_C}\left\{\frac{p_2-\alpha_Y}{p_3-\alpha_Y}\times\frac{p_3-\alpha_X}{p_4-\alpha_X}\times\left[X_Z(\frac{p_4}{p_{5Z}}C_5-C_4)+X_S(\frac{p_4}{p_{5S}}C_5^{'}-C_4^{'})+X_JC_5^{''}\right]-\left[(C_1+C_2)+\frac{(p_2-\alpha_Y)C_3}{p_3-\alpha_Y}\right]\right\} \quad (1)$$

Where p_1~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、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; α_C is the grade of mixed with gangue; α_Y is the grade of pre-selection process of removing the ore; α_X is the tailings grade; p_{5Z} is the pellets grade; p_{5S} is the sintering grade.

(1) The minimum of the total cost C is the goal and could be presented in the form of Equation (2).

$$\text{Min}C=\sum_{i=1}^{4}t_if_i(p_i,p_{i+1}) \quad (2)$$

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.

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

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

Where p_1~p_5 is the each link for the corresponding grade; α is the grade factor; δ_2 is the tailing grade of pre-selection process of ore; δ_3 is the mineral processing aspects of tailings grade; k_1, k_2, k_3 are mining, pre-selection, mineral processing aspects of waste environmental factors, respectively; δ_4 is the Iron dissipation factor on pelleting stage.

And three evaluation index tools are developed by computing the derivative of the above model on this basis.

(1) Grade profit active index (GPAI). It refers to the ratio of system's per-unit profit to the unit grade, which is used to measure the activity levels of system effectiveness of process grade, reflecting the extent of influence of every engineering aspect on the overall effectiveness. The larger grade-effective active index is, the more influence of the aspect on system performance and vice versa is. Application of this index can find out a max impact aspect on profit, focus on the implementation of technical innovation, and also come true "Key breakthrough" of critical technology. The basic formula is presented by Equation (4).

$$P_i^{\mathrm{GPAI}} = \frac{\mathrm{d}B}{\mathrm{d}p_i} = \frac{\mathrm{d}f_i(p_i)}{\mathrm{d}p_i} \tag{4}$$

(2) The grade cost margin index (GCMI). It refers to the change of unit grade of mining engineering. The relative change rate of total cost between processes is used to measure the actual cost and the marginal cost of the degree of deviation from the optimal process, reflecting all aspects of the project cost control. Grade cost margin index changes between -1 to 1. Index greater than zero means higher grade, larger index, and farther deviation from the optimal value; while T index less than zero means lower grade, smaller index, and closer deviation from the optimal value; when index is equal to 0, grade reaches the optimal value. Application of the index can optimize the quality of every aspect grade, strengthen the cost control of the whole process, and achieve the "linear ganged" between processes. The basic formula is presented by Equation (5).

$$P_i^{\mathrm{GCMI}} = \frac{\mathrm{d}f_i + \lambda_{i+1}\mathrm{d}f_{i+1}}{(f_i + \lambda_{i+1}f_{i+1})\mathrm{d}p_i} \tag{5}$$

(3) Grade environmental effect index（GEEI）. Grade-environmental effect index refers that under the variation of unit grade situation，the relative change rate of total waste emission (environmental impact) can reflect all aspects of project waste control. Grade-environment marginal index is variable in the range from －100 to 100. When the index is greater than zero, it means the higher grade, the greater index and farther deviation from the optimal value. When the index is less than zero，it means the lower grade, the smaller index and closer deviation from the optimal value. When the index is equal to 0, Grade reaches the optimal value. Application of this index can correctly handle the relationship between resource recycling and waste emission and also take economic and environmental benefit into consideration by Equation (6).

$$P_i^{\mathrm{GEEI}} = \frac{\mathrm{d}E}{E\mathrm{d}p_i} \tag{6}$$

The above evaluation index can be regarded as a bottleneck of quantity index analyze , focus on the development of the whole system function and make a breakthrough in technology and engineering management.

2.4 Objective laws of "grade decision-based multi-system integration" project mode

Through analyzing and deriving the mathematical model of "grade decision-based multi-system integration" project mode, the following laws are found.

(1) The relationship between mined ore grade and pretreatment cost is hyperbolic. In the active zone, upgrading of mined ore grade has an obvious effect on pretreatment cost, while in the clam zone, this situation see an opposite.

(2) The relationship between grade of crude ore and processing cost is hyperbolic. In the active zone, upgrading of grade of crude ore has an obvious effect on processing cost, while in the clam zone, this situation see an opposite.

(3) The relationship between concentrate grade and processing cost is linear. The cost of processing increases with the decline of concentrate grade.

The above-mentioned laws are significant theory basis to carry out linkage optimization of the mining Engineering.

3 The practice and results of "grade decision-based multi-system integration" project mode

The "grade decision-based multi-system integration" project mode provided large-scale resource exploitation with support. Ansteel has implemented Anshan eastern mining area construction according to the mode. Anshan eastern mine area has the largest lean ore resource in the world with resources reserved of 17.2 billion tons and the mine area has reached 58km^2. Because of the lack of experience of the construction of large and complex mining area, it has never been exploited for 80 years since it was found. Major reasons are as follows: ① Large mining area, many gobs, bad performance of drilling and blasting, difficult mining condition; ② Low ore grade, complex mineral composition, highly-difficult processing; ③ Various ore types(four types), scattered mining areas (6 mining areas and 11 mining sites), difficult engineering organizations.

Since the tenth-five-year plan, Ansteel mining has implemented integrated management of information platform, constructed collaborative innovation mechanism, focused on gang control of global optimization and pursued low-carbon operation methods, and carried out large scale, low-cost and high efficient exploitation of eastern mining area.

3.1 Implementation based on integrated management of information platform

Ansteel mining has integrated the person, asset, object, energy, technology, and information of engineering process and optimized element, structure, function and efficiency. ① Intelligence Integration. Through "project decision-making group", "technological creative group", "public relations team" shapes, integrating knowledge and skills of managers, professionals and front-line employees. ② Organization integration. Ansteel mining has built matrix organization structure, management function can link project management vertically and cover professional management transversally. ③ Process integration. Ansteel mining has built "Five in One" engineering management system including research, project, management, construction and operation and coming true integration of lifetime of Mining Engineering. ④ Technology integration. Ansteel mining has established the core technological system including reconnaissance, mining, processing, sintering and briquette and guarantee engineering technology. ⑤ Information integration. Ansteel mining has established "five-level structure" information management system including automatic data collection, automatic process controller, MES, ERP and smart decision analysis.

3.2 Setting up collaborative innovation mechanism

Organization mode varied from independent and close mode done by Ansteel steel to whole-collaborative mode done by Ansteel uniting 216 other cooperation. Strategy-companion management has come true by lowliest place elimination, profit distribution, information feedback, research and innovation skills, and assessment and improvement. Engineering management can be divided into five periods: research, project, management, construction and operation. 25 factors during five periods are considered and creative resource, forming research and production collaboration, technology strength consolidation, advantage technology integration is integrated and deployed.

3.3 Focus on linkage control of the global optimization

Ansteel mining broke original "various mixed processing in a single mine" engineering organization mode and established a new engineering organization mode: large area mining, networking ore blending and differentiated separation. Also we used a three-dimensional transport network consist of trail, road and big curvature sealing-tape machine, distributing four different types refractory ores in six working areas and ten mining areas to four different process concentrating mills, which could ensure areas jointing, mining and dressing intercommunication, similarity collection and differentiated separation, improve efficiency of mining, blending and processing, and cut the cost.

3.4 Pursuit of low carbon operation

In the exploitation process of eastern mine resource, we planned energy conservation, environment protection and ecology management together in mine areas. Every year we collect above 12 million tons of low grade ore equal to the production of an outsize mine, use large and modern technological equipment, and eliminate high-energy consumption equipment. Under the markup of consumption energy conditions, ratio of unit energy consumption decreased by 20%; qualified rate of dust and pollution factors reached to 97.2% and 96% respectively. The production of sewage disposal approached to 0 greening coverage rate of land reclamation reached to 43.5% to be industry-leading level. Referring to the difficult security management problem of outsize complex mines, we fulfilled the concept of "people oriented, zero tolerance for major accidents", took the measures of "safety standardized construction" and "safety evaluation", built information safety management system and guarantee safety operation of the whole engineering process.

3.5 The implementation results of "grade decision-based multi-system integration" project mode

After years of construction and development, Ansteel mining has had the overall competitive advantages on domestic industry, especially in the technology of mining and processing reaching to world leading level, leading the development of Chinese mining industry. The overall implementation results are as follows.

First, a world-class oversize poor hematite zone is built. The mining capacity of Anshan east mine in the beginning of the 10th five year went from 10 million tons to 33 million tons. The concentrate grade raised from 62% to 67.5% with 520 yuan cost per ton (46% lower than the price of imported ores), and the annual profit, 3.6 billion yuan.

Second, the operation's competence is improved. Ansteel mining has become an industry leading enterprise in domestic marketing. The technology of mining and processing has reached a word-class level and the production cost of domestic Iron ore concentrate ranks from the six to the top, forming competitive advantage with imported ore. In the recent five years, Ansteel mining accumulated the profit reaching 30.4 billion yuan, paid taxes to 11.6 billion yuan and won seven Country Technological and Management Creation Awards as well as 35 provincial awards.

Third, Ansteel mining has lead the improvement of mining industry. The high-efficient exploitation and utilization achievement of depleted iron ore resources in Ansteel mining operation has been applied to 10 mines and obtained significant economic benefits and social benefits, promoting the rapid development of Chinese mining industry.

Finally, Ansteel mining has supported the national resource strategy. The successful practice of "grade decision-based multi-system integration" project mode activated abundant lean ore resource, applied the China's biggest ore mine project, supported self-sufficient resource strategy and eventually played a more significant role in maintaining national security.

4 Conclusions

(1) "Grade decision-based multi-system integration" proj-

ect mode reflects the mind of engineering philosophy in production practice concretely. It stems from engineering philosophy and develops in engineering practice based on engineering sense and methodology of engineering philosophy. Only by projecting mining engineering with the philosophical view and making breakthroughs of management thinking limit and setting up scientific engineering sense, can we open up a new situation of resource exploitation. We need be conscious of solving engineering problem with engineering philosophy thinking in engineering practice. Practice had proved that only examining engineering with engineering philosophy insights, can we create a better world and complete greater and long-term career.

(2) "Grade decision-based multi-system integration" project mode provides theoretical basis and methods of practice for management of mining engineering. "Five grades ganged" project mode reveals the intrinsic law of mining activities. It worked out the various kinds of contradiction relationship in mining project and provided theoretical basis and methods of practice for management of mining engineering. We should develop engineering management with references of engineering philosophy, system theory, environment, managerial economics, information science and other relevant theories and establish management theory, models and methods suitable for different engineering characteristics, and maximize the benefits of the project.

(3) The popularity of "grade decision-based multi-system integration" project mode will lay the foundation for the ability of protection of national resources. The solution to the contradiction between engineering and technology will lay the material foundation for changing passive situation that China's iron ore resources was in control of others. At the national level we should research and judge the exploration law of ore resources, establish a sound strategy for resource security system as soon as possible, accelerate the development of our own resources development, improve resource self-sufficiency rate and stabilize the price of imported ore to protect national economic security.

(4) "Grade decision-based multi-system integration" project mode will have played a positive role in building a harmonious society. Just like Engels said: "We should not be too intoxicated with victory against our human nature. For each victory, nature takes its revenge on us". "Grade decision-based multi-system integration" project mode promotes ecological ethics and low-carbon operation and reflected the change of the concept from the conquest of nature to harmonious Engineering. Engineering activities should follow the law of nature and community, adhering to the people-oriented and environmentally friendly, promoting the harmonious development of human, nature and community.

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