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Application of NSR-AISC Method in Reserve Estimation and Technical Economic Evaluation of Low-Grade Polymetallic Deposits: Taking a Low-Grade Copper-Molybdenum Mine in Guangdong Province as an Example

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Abstract

The development and utilization of low-grade polymetallic deposits with strategic mineral resources is one of the important measures to alleviate the current high dependence on strategic mineral resources in China. However, domestic mining enterprises and most mining consulting and design institutes usually use general industrial indicators to carry out reserve estimation and technical and economic feasibility studies on low-grade polymetallic deposits, which cannot truly reflect the economic value of such deposits. The article expounds on the definitions of net return value (NSR) and on-site total maintenance cost (AISC) of common ore smelters in the evaluation of overseas mineral resources. Taking a low-grade polymetallic copper-molybdenum mine in Guangdong Province as an example, comparing the research results showed the NSR-AISC method and the general industrial index method in low-grade polymetallic deposit. There are huge differences in the results of reserve estimation; through the further introduction of Taylor's formula and the research results on the relationship between investment intensity and production scale, a more reasonable mine life and investment scale are recommended, and a more in-depth comparative study has been carried out in the dimension of technical and economic indicators. Based on the comparative study of the above two methods in reserve estimation and the evaluation results of technical and economic indicators, the author believes that the NSR-AISC method can better reflect the true value of low-grade polymetallic ore projects, and should be popularized and applied in resource evaluation and development practice. This article further describes the application status of the NSR-AISC method for reserve estimation and the evaluation of technical economic indicators, and suggests the main points that should be paid attention to in the use of the NSR-AISC method.

Keywords

NSR-AISC Method, General Industrial Indicators, Low-Grade Polymetallic Ore

1. Introduction

China is currently in the stage of rapid industrialization, and strategic mineral resources are an indispensable material foundation for economic and social development. In recent years, with the rapid development of the new generation of information technology, high-end equipment manufacturing, new energy and other strategic emerging industries, the demand for strategic mineral resources in China will continue to remain high. China's strategic mineral resources are generally characterized by small total volume, low grade, poor resource endowment and high dependence on the outside world. With the gradual depletion of near-surface deposits and the increasing difficulty of exploration, the development and utilization of low-grade polymetallic deposits in the inventory of strategic mineral resources has become one of the most important measures to quickly improve the self-sufficiency rate of strategic mineral resources and reduce external dependence. Therefore, the author believes that the strength and accuracy of low-grade polymetallic deposit resource reserves and technical and economic feasibility studies of strategic mineral resources inventory should be improved. Taking a low-grade copper-molybdenum ore in Guangdong Province as an example, this paper introduces the application of NSR-AISC method in the estimation of low-grade polymetallic ore reserves and technical and economic feasibility evaluation.

2. NSR and AISC

With the continuous improvement of mining industrialization, more and more low-grade polymetallic deposits to be developed are gradually listed as research objects by mining enterprises and included in the development plan as replacement mineral resources, making it possible to develop low-grade polymetallic mines in stock [1]. However, at present, most mines and mine design consulting units in China mainly use general industrial indicators to estimate the reserves of low-grade polymetallic ore and conduct technical and economic feasibility studies. As a result, the grade of most ores is lower than the general industrial indicators and cannot correctly reflect the economic value of low-grade polymetallic deposits. The conclusion is that the reserves are small and the technology and economy are not ausible, which leads to the low development and utilization rate of low-grade polymetallic deposits in China.

In the process of overseas resource evaluation, the author found that the reserve estimation report and technical-economic feasibility study report that meet the JORC and NI-43101 standards often define ore with an NSR value greater than AISC as reserves, and replace general industrial indicators for ore reserve estimation and technical economy. Feasibility study. NSR has been widely used in the European and American mining markets in the 1990s, especially in polymetallic deposits. After 2000, it began to be studied and cited by some Chinese scholars. The definition of NSR is, the sales of mineral products generated per ton of ore minus the net value of expenses incurred outside the mine; expenses outside the mine include product departure [2]. All expenses incurred in the process from the mine to delivery to the smelter usually include product transportation costs, natural losses during product transportation, smelting processing fees and sales costs, etc. AISC refers to the total maintenance cost that occurs at the mine site during the operation of the mine. According to the cost category, it can be classified into mining costs, beneficiation costs, administrative costs and continuous capital expenditure [3].

3. Comparative Study on the Use of NSR-AISC Methods and General Industrial Indicators for Reserves and Technical and Economic Feasibility Evaluation

In the practice of overseas mine production, the NSR-AISC method has been used to estimate the reserves of deposits and the technical and economic feasibility evaluation has achieved good results. However, in China, this method has only been recognized by a few mining companies with a high degree of internationalization. It has not been recognized by the vast majority of mining companies and mine design consulting units, and the scope of application is narrow. By comparing and studying the reserves and technical economic feasibility results of multiple low-grade polymetallic ore projects, the author believes that the NSR-AISC method is more accurate and effective in evaluating low-grade polymetallic ore than the use of general industrial indicators in reserve estimation and the evaluation of technical and economic indicators. The following article takes a low-grade copper-molybdenum ore in Guangdong as an example, using the NSR-AISC method and the general industrial index method for reserve estimation and mine economic value evaluation. Although industrial index method requires a very high degree of social credibility, the results show that the NSR-AISC method is more in line with the actual development of mine development, gives full play to the economic value of low-grade polymetallic mines, and low-grade polymetallic mines, and improves the utilization rate of low-grade polymetallic mines.

3.1. Basic Situation of a Low-Grade Copper-Molybdenum Mine in Guangdong

A low-grade copper-molybdenum mine is located in the western part of Guangdong Province. It is a typical porphyry-type low-grade copper-molybdenum polymetallic deposit. As early as 2008, it was known that the ore resources were 570 million tons, containing 980,000 tons of copper, 0.17% copper grade, 260,000 tons of molybdenum, and 0.05% molybdenum grade. The resource quantity from field studies is shown in Table 1. Some ore bodies are exposed to the surface, bodies are exposed to the surface, and it is planned to adopt conventional perforation blasting open-pit development. Existing beneficiation experiments have shown that the ore can obtain a better beneficiation index by using the SABC grinding process and the copper-molybdenum-sulfur mixed flotation-sulfur-inhibition floating molybdenum copper-molybdenum-copper separation flotation process. The details of the beneficiation indicators are shown in Table 2.

Table 1. Mineral resources of a copper-molybdenum mine in Guangdong.

Scenarios	Ores	Copper Metal Contained	Copper Grade	Moly Metal Contained	Moly Grade
Industrial ores	190 MT	0.36 MT	0.19%	0.13 MT	0.07%
Low-grade ores	380 MT	0.62 MT	0.16%	0.13 MT	0.03%
Total	570 MT	0.98 MT	0.17%	0.26 MT	0.05%

Table 2. The mineral processing parameters of a copper-molybdenum mine in Guangdong.

Products	Ores (t/d)	Production Rate (%)	Conc. Grade (%)		Conc. Recovery (%)	
			Copper	Moly	Copper	Moly
Copper Conc.	265	0.76	21.00	0.35	86.00	5.41
Moly Conc.	27	0.08	0.30	53.00	0.13	84.00
Tailing	34,708	99.16	0.02	0.005	13.87	10.59
Feed	35,000	100	0.19	0.05	100	100

3.2. Use General Industrial Indicators for Estimation

3.2.1. Reserve Estimation

Using general industrial indicators for reserve estimation, the industrial molybdenum ore body is circled with molybdenum boundary grade of 0.03% and industrial grade 0.06% (or the industrial copper ore body is circled with copper boundary grade of 0.2% and industrial grade of 0.4%). It is estimated that the total amount of industrial copper and molybdenum ore in the project is 190 million tons, and the molybdenum level is flat. The average grade is 0.07%, and the average grade of accompanying copper is 0.19%.

3.2.2. Evaluation of Technical and Economic Indicators

The technical and economic feasibility study of the mine uses all industrial ore bodies to delineate the open-pit realm. The total amount of rock ore in the boundary is about 903 million tons, and the stripping ratio is about 3.77. It is calculated with an annual processing capacity of 10 million tons. Considering the depletion rate of 5% and the loss rate of 5%, it is concluded that the average selected grade of ore molybdenum is 0.07%, the average selected grade of copper is 0.18%, and the mine life is about 20 years. Referring to the results of the ore dressing experiment, the recovery rate of beneficiation is 86% copper and 84% molybdenum. It is calculated that the annual product level of the project is 45% of the molybdenum concentrate is 13,066 tons, and the amount of molybdenum metal content is 5,880 tons; the grade of copper concentrate is 77,400 tons, and the grade is 15,480 tons of copper metal. Molybdenum concentrate is calculated according to 2300 yuan/ton (excluding tax), and copper concentrate is calculated according to 10,000 yuan/ton (excluding tax), and converts copper into equivalent molybdenum: ratio = (copper concentrate copper content price × copper recovery rate)/(copper concentrate copper content price × copper recovery rate) = (50,000 × 86%)/230,000×84%) ≈ 0.22, the selected grade of the annual ore is about 0.11% of the equivalent molybdenum, and the annual sales volume is about 2.013 billion yuan.

The technical and economic feasibility study report shows that the initial investment of the project under the production scale is about 3.8 billion yuan, the total cost of mining is about 9.03 billion yuan, the mining cost is about 48 yuan/ton ore, the beneficiation cost is about 60 yuan/ton ore, the administrative management fee is about 15 yuan/ton ore, and the sales cost is about 5 yuan/ton of ore. Stone, other costs are about 11 yuan/ton ore, amortization depreciation cost is about 20 yuan/ton ore, mining rights transfer income is about 4 yuan/ton ore, and the total cost of ton ore is 163 yuan/ton, of which the production cost is 143 yuan/ton. The demonstration results of technical and economic indicators show that the net cash inflow of the project after tax is about 488 million yuan per year, and the cumulative net cash inflow of the project in the whole life cycle is about 9.322 billion yuan. At a discount rate of 10%, the net present value of the project is −55 million yuan, and the internal rate of return on all investment finance (IRR) is only 9.7. 8%, the static payback period is 10.24a (see Table 3 for details). As a green space project, the net present value is −55 million yuan, and the IRR is less than 10%. These two technical and economic indicators are poor and do not meet the investment requirements of domestic mining enterprises.

Table 3. General industrial indicators reach the annual production project technical and economic index table (discount rate 10%).

Parameters	Reserves	Moly grade	Copper grade	Capacity	Investment	Cost
Values	190 Mt	0.07%	0.19%	10 Mt	3.8 Billion	163 yuan/t
Parameters	Sales Volume	Net Cash Flow	Net Profit	NPV	IRR	Payback Period
Values	2.013 Billion yuan	488 M yuan	384 M yuan	−55 M yuan	9.78%	10.24a

In summary, the use of general industrial indicators to estimate reserves and invest and operate according to the designed production capacity. The technical economy of the project is not feasible.

3.3. Estimation Using NSR and AISC Methods

3.3.1. Estimation of Reserves

1) Preliminary estimate of reserves

The feasibility study report on the estimation of general industrial indicators shows that the AISC of the ore in the boundary is about 138 yuan/ton. Therefore, under the condition that the pit boundary and production scale remain unchanged, the NSR-AISC method is used to estimate the reserves of the project, and the ore of NSR greater than 138 yuan/ton can be listed as reserves.

According to the product sales and pricing method of domestic molybdenum concentrate, the NSR calculation formula of molybdenum ore is simplified, and the NSR of tons of molybdenum ore = molybdenum concentrate unit price × molybdenum grade × (1-poor rate) × molybdenum recovery rate − sales cost, from which molybdenum grade = (NSR + sales cost)/molybdenum recovery rate can be derived. ÷ (1-depletion rate)/the unit price of molybdenum concentrate. It is known that the ore with NSR greater than 138 yuan/ton is the reserve. The price of molybdenum concentrate is 230,000 yuan/ton, the mining depletion rate is 5%, and the molybdenum recovery rate is 84%. It is obtained that the molybdenum grade > (138 + 5)/84%/95%/230,000 is the reserve. It is calculated that when the molybdenum grade is >0.078%, NSR > AISC = 138 yuan/ton, and the ore can be included in the reserves. According to the equivalent calculation results, the value ratio of copper-molybdenum is 0.22. When the copper grade in the ore is greater than 0.35%, the ore NSR > AISC = 138 yuan/ton, and the ore can also be listed as reserves. Considering that the ore in the mine is dominated by molybdenum ore body, in order to facilitate the calculation, the reserves are estimated with a molybdenum equivalent grade of 0.078% as the boundary grade, and the ore reserves in the mine are about 331 million tons.

2) Iterative optimization of reserve estimation results

According to the preliminary estimates, the amount of ore in the mined pit is more than 138 yuan/ton, with a total of 331 million tons. It is known that the total cost of mining of 903 million tons is about 9.03 billion yuan, the ore reserves mined have increased from 190 million tons to 331 million tons, and the mining cost of tons of ore has been reduced from the original 48 yuan/ton to about 27 yuan/ton. The tons of ore AISC has been revised, and the tons of ore AISC have been revised from the original 138 yuan/ton. The ton is reduced to 117 yuan/ton. It is calculated that the equivalent molybdenum grade is >0.067%, the ore NSR > AISC = 117 yuan/ton of ore, and the ore reserves in the mine are about 434 million tons. According to the newly estimated ore reserves, AISC is calculated again, and NSR correction and grade and reserve estimation are carried out again… Through continuous iterative calculation and recursion, it is found that the limit value is 0.055% of the equivalent molybdenum grade, and the highest utilization rate of the valuable elements in the pit is obtained. At this time, the ton of ore AISC in the mine is about 100 yuan/ton, the ore reserves in the mine are about 520 million tons, and the average grade of equivalent molybdenum is 0.092%.

3.3.2. Conclusion of Technical and Economic Indicators

1) Preliminary results of technical and economic indicators

According to the ore reserves of 520 million tons, the production scale of 10 million tons/year, the investment of 3.8 billion yuan, the ton of ore AISC according to 100 yuan/ton, the average grade of the ore molybdenum equivalent is 0.092%, the depletion rate is 5%, the recovery rate is 84%, and the price of molybdenum concentrate is 230,000 yuan/ton. Certificate. The demonstration results show that the cumulative net cash flow of the project is 25.365 billion yuan. When the discount rate is 10%, the net present value of the project is 670 million yuan, the IRR is 11.89%, and the static investment payback period of the project is 9.99a, which basically meets the investment requirements of domestic mining enterprises.

2) Preliminary production scale

The preliminary demonstration results of technical and economic indicators show that the scale is 10 million tons/year. The mining technical and economic indicators have met the basic investment requirements of mining companies, but the life of the mine is more than 50 years. Combined with scale benefits and mining practice, it is preliminarily judged that the scale of mine production is not the best result. Through the life of the mine, the production scale and investment are optimized to maximize the economic benefits of the mine.

Taylor's research results on mine life have been widely used in mine practice at home and abroad. After in-depth comparative research on a large number of mines, Taylor put forward two empirical calculation formulas [4] to calculate the best life of the mine. Formula 1 shows the best life of the mine = 6.5 × (ore volume/100 tons) 1/4, substituted into this project, the best life of the mine = 6.5 × (520) 1/4 ≈ 31 years; formula 2 shows the best life of the mine = 0.2 × (ore volume) 1/4, and the best life of the mine in this project = 0. 2 × (520,000,000) 1/4 ≈ 30 years. Through the above two Taylor formulas, it can be judged that the optimal life of the project is about 30 years. Considering the climbing of mine output in the first year and the decline in production capacity in the last year, the production capacity of the project is optimized to 17.24 million tons/year.

There are three main comparative research methods of mine production scale and total investment, namely, the production scale index method, the regression correlation method and the unit output investment index method. Among them, the main research objects of the production scale index method are similar mines [5] [6]. Considering that the object of this study is the same mine, it is reasonable to use the production scale index method for investment estimation. The Production Scale Index Law stipulates that the investment amount of the project after the production capacity is increased = the original scale investment amount × (production scale/original production scale) 0.6, and the amount of investment after the expansion of this project = 3.8 billion yuan × (17.24 million/10 million) × 0.6 ≈ 5.268 billion yuan.

3) Results of technical and economic indicators after optimized production capacity

When the annual production and treatment scale is 17.24 million tons/year, the project investment scale is 5.268 billion yuan, and the selected equivalent molybdenum grade is 0.092%. The scale effect reduces the cost by 5 yuan/ton ore, AISC is about 95 yuan/ton ore, the recovery rate of molybdenum beneficiation is 84%, and the unit price of molybdenum concentrate is 2300 yuan/ton, equity is 2.3% of sales. The demonstration results of technical and economic indicators show that the annual sales revenue of the project is 2.844 billion yuan/year, the sales cost is about 1.638 billion yuan/year, the net cash flow after tax is 939 million yuan/year, and the cumulative net cash inflow of the whole life cycle project is about 272.40 million yuan. With a 10% discount rate, the net present value of the project is 2.373 billion yuan, the IRR is 15.22%, and the static recovery period of the project is 8.11a.

3.4. Comparative Research Conclusions

The comparative study of the use of general industrial indicators and the use of NSR-AISC method in terms of reserve estimation and technical and economic feasibility, the research results show that the NSR-AISC method is more competitive in all indicators. In terms of reserves, according to general industrial indicators, there are only 190 million tons of economically mineable ore reserves in the open-air realm, while the mineable reserves of the NSR-AISC method have increased to 520 million tons, greatly improving the efficiency of resource utilization. In terms of technical and economic indicators, the NSR-AISC method reflects absolute advantages in IRR and net present value. General industrial indicators are used for reserve estimation. The results of the technical and economic feasibility study show that the net present value of the project is less than 0 and the IRR is less than 10%, and the project is judged to be technically and economical. The NSR-AISC method is used to estimate reserves. The results of the technical and economic feasibility study show that the net present value of the project is 2.373 billion yuan and the IRR is 15.22%. The project is technically and economically feasible, and can generate a very considerable, stable and long-term cash flow, with excellent investment returns. For details, see **Table 4**.

Table 4. Comparison of mine reserves and technical and economic indicators (10% discount rate).

Reserves	Equivalent Moly Grade		Capacity	Investment	AISC	Description
190 MT	0.112%		10 MT	3.8 Billion	143 yuan/t	Routine
520 MT	0.092%		10 MT	3.8 Billion	100 yuan/t	NSR
520 MT	0.092%		17.24 MT	5.3 Billion	95 yuan/t	Optimization
Sales Volume	Annual Cash Flow	Total Cash Flow	NPV	IRR	Payback Period	Description
2.013 Billion yuan	488 M yuan	9.322 Billion yuan	−55 M yuan	9.78%	10.24a	Routine
2.844 Billion yuan	507 M yuan	25.365 Billion yuan	670 M yuan	11.89%	9.99a	NSR
2.844 Billion yuan	939 M yuan	27.24 Billion yuan	2.373 Billion yuan	15.22%	8.11a	Optimization

The comparative research results show that when evaluating low-grade polymetallic deposits, the NSR-AISC method can be used to estimate reserves more accurately and improve resource utilization. After optimizing the production capacity and cost of the Taylor's formula and production scale index method, the net present value and return on investment of the mine are greatly improved, so that some inventory low-grade polymetallic deposits that are judged to be unfeasible in terms of technology and economy by general industrial indicators have development value, and provide technical support for the development of low-grade polymetallic ores in inventory. It is an important measure to improve the self-sufficiency rate of some key metals. It can be promoted and applied in resource evaluation and mine development practice.

4. Application Status and Key Points of NSR-AISC Method

4.1. Success Stories

At present, some porphyry copper mines use the NSR-AISC method to estimate the ore reserves and technical economic evaluation, so that the selected grade of the mine is lower than the general industrial index, and has achieved a good investment income. Due to the limitation of space, I will not list them one by one. This article only lists the high internationalization of Zijin Mining in the flagship. Successful application cases on the project drive Dragon Copper Mine. According to the latest news released by Zijin Mining on June 29, 2024, the NSR-AISC method was used in the Qulong Copper Mine, a flagship project in Tibet, to carry out the estimation of reserves and the demonstration of technical and economic indicators, reducing the boundary grade of copper reserves in the mine to 0.17% and the average grade of reserves to 0.32%. It is far lower than the general industrial index. The return on project investment is more than 10%, and the optimized net present value of the project far exceeds the consideration of mergers and acquisitions.

4.2. Risk Cases

In reality, there are also many failure cases. After investigation and research, the author believes that the main reason for the failure is that the research on the resource endowment of polymetallic deposits is not in-depth enough, resulting in the inclusion of ores with no economic value in reserves in the process of reserve denomization and technical and economic evaluation, so that the results of technical and economic feasibility evaluation are issued. There is a major deviation.

Case 1, a rare metal mine in China contains a variety of valuable minerals such as niobium, tantalum and rare earth. The grade of niobium even meets the requirements of general industrial indicators in China. Without in-depth research on resource endowment and no qualified products and mature process, it is assumed that the ore NSR value and AISC value are assumed, and N The SR-AISC method carried out a reserve calculation and a technical and economic feasibility study, and the research results gave a positive conclusion: the project has huge reserves and good economic benefits. However, in the process of project promotion later, it was found that qualified concentrate products could not be produced through the beneficiation process, and there were almost no ores greater than AISC in NSR, so the project has not been developed so far.

Case 2, a silver polymetallic ore project in Bolivia is in the exploration stage. Under the condition that the degree of source endowment research is not in-depth and there is no mature process to indicate the product form, the NSR-AISC method is directly used for reserve estimation, and the boundary grade is estimated at NSR > AISC = 9.2 USD/ton. After calculating 540 million tons of resources, the average grade of silver in the ore is 13.6 grams per ton, and the average grade of lead + zinc is 0.97%. The author deeply investigated and studied the same type of mines in production, and compared the project resource endowment. It is believed that the project cannot select qualified lead and zinc concentrate products, and the silver element recovery rate is also far lower than the estimated recovery rate of the project party. The NSR value of the ore lacks technical support, and the project is important in reserve estimation and technical and economic evaluation. Big risk.

4.3. Application Points

The above two risk cases are mainly due to the inability to form qualified sellable concentrates, which leads to the deviation of NSR calculation results, which affects the evaluation results of technical and economic indicators. In resource evaluation, there are often some design processes that cannot recover some elements, but these unrecoverable elements are included in the ore in the NSR calculation. In the value, the wrong technical and economic evaluation results are given. This kind of phenomenon belongs to the use of NSR-AISC method without following objective laws. These situations usually also occur in the estimation of reserves and the demonstration of technical and economic indicators of deposits such as copper-gold oxide deposits, lead-zinc oxide deposits and copper-zinc deposits. To sum up, the author believes that when carrying out the NSR-AISC method for reserve estimation and technical and economic feasibility evaluation, in-depth research and experimentation should be carried out on the resource endowment of ore, mineral selectivity, and product quality of beneficiation concentrate, and the corresponding report should be submitted as the basis for evaluation.

5. Conclusions

Through a comparative study of the results of the NSR-AISC method and the general industrial index method in a low-grade copper-molybdenum polymetallic ore in Guangdong, and combined with the application status of the NSR-AISC method, the following conclusions are drawn in this paper:

1) The NSR-AISC method can more accurately estimate the reserves of low-grade polymetallic deposits and improve the resource utilization rate of low-grade polymetallic deposits. Combined with Taylor's formula and produc-

tion scale index method to optimize the production capacity and cost, it can greatly improve the net present value and return on investment of low-grade polymetallic deposits. It provides technical support for the development of low-grade polymetallic ore in stock, which is an important measure to improve the self-sufficiency rate of some key metals. It should be promoted and applied in resource evaluation and mine development practice.

2) The research on the resource endowment of low-grade polymetallic deposits should be strengthened to ensure the accurate and reasonable use of the NSR-AISC method in the estimation of reserves and the evaluation of technical and economic indicators of deposits.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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