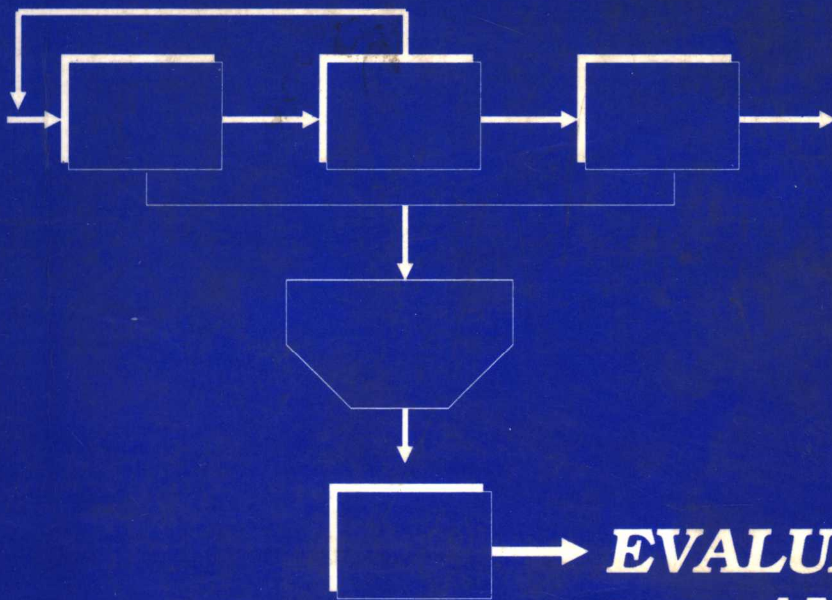

EVALUATION AND OPTIMIZATION OF METALLURGICAL PERFORMANCE

SOCIETY FOR MINING METALLURGY AND EXPLORATION INC.
AIME

editors:

Malhotra
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EVALUATION AND OPTIMIZATION OF METALLURGICAL PERFORMANCE

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FOREWORD

The cyclical nature of the mineral industry has put increasing pressure on the ***Process Engineer*** to constantly evaluate and optimize plant metallurgical performance. Hence, the Process Engineer plays a key role in the economic viability of the mineral company which is dependent upon maximizing mineral recoveries at minimum cost.

The changing environment has made it mandatory for the Process Engineer to become familiar with all facets of mining activities which impact metallurgical performance: management philosophy, ore mineralogy, mining methods, data collection and evaluation techniques, economics, environmental issues and product quality. Numerous publications have been written on these topics, ***but no single publication exists as a compilation of articles dealing with innovative methodologies used to improve metallurgical efficiencies of operation***.

The goal of this conference is to present the tools needed for plant evaluation and optimization written by leaders in their fields. This publication also includes case studies illustrating the use of the techniques discussed in this text to solve real-life problems encountered in plants.

Chapter authors need a special mention. They were gracious to share their practical experience with all of us and have jointly contributed to the actual success of this symposium.

We extend our sincere and heart-felt thanks to all the members of the Symposium Organizing Committee and the Session Chairpersons for their timely and valuable help.

Finally, special thanks to Darline Daley, Meetings Manager, and Marianne Snedeker, Manager of Book Publishing, of SME for their patience and consideration; and Lora Abcarian, Administrative Assistant, Resource Development Inc., for her valuable input and organization.

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MANAGEMENT

Chapter 1

ECONOMIC CRITERIA FOR DECISION MAKING

by

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ABSTRACT

Modelling of cash flows and calculation of net present value of rate of return over the expected life of a mine/processing unit continues to be the accepted basis for mineral investment decision-making. The computer and spreadsheet programs have greatly improved ability to perform sensitivity and risk analysis, hence our ability to deal with key analytical problems. These problems of cash flow analysis result from the necessity of forecasting an uncertain and risky future. Cash flow models begin with the critical assumption of a "design basis", then integrate all of the variables relevant to the investment decision including forecasts of price, cost, taxation, financial conditions, and company strategy. Alternate "scenarios" portray possible future outcome of the investment decision. The potential for straying from reality is enormous. The computer has eliminated the time consuming hand calculations from the cash flow analysis, but the analyst still struggles with the risk of trying to predict "how the project will *really* turn out".

INTRODUCTION

The creation of a new mine and plant design and the conversion of that design to a cash flow model for investment analysis of the project has always been, at least in this author's view, the most creative and exciting activity in mineral economics. To be successful such effort must involve close cooperation between the many design engineers, geologists, cost estimators, project planners and schedulers, price and cost forecasters, and others that contribute to an investment analysis. If the project is close to a commitment to spend millions of dollars for development, the pressure for an accurate forecast of the future is extremely high. If the project is in the exploration or pre-feasibility stage the money involved may less but the task is even more challenging because of the lack of hard data and the need to keep moving in the profitable direction. The objective of this paper is to describe the "state of the art" in cash flow analysis today, to outline the problems we face and the response of the industry in it's effort to develop a realistic and professional approach to modeling the mineral investment. The discussion is in terms of a hypothetical $165 million copper investment that subsequently encounters many of the problems associated with current mineral investment.

THE CASH FLOW MODEL

The cash flow pattern shown in figure 1 is that generated by a constant 1990 dollar analysis and, in order to be specific, a series of critical "most likely" assumptions about the future. The model is hypothetical - a composite of the author's experience, useful to describe some of the pitfalls of investment analysis. In this scenario, the investment in mine, mill and working capital is $165 million over a period of 7 years. beginning in the 8th year constant dollar cash flows are positive, averaging $69.6 million per year including the start-up years 8 and 9 and the shut-down year 31. Copper revenues average $237.3 million per year and by-products $6.8 million per year over mine life. These results assume an ore grade of 0.7% copper, a constant dollar copper price of $1.00 per pound and a total cost before taxes and replacement capital expenditures of $7 per ton of ore. The key metallurgical assumptions are reflected in the cost for milling, smelting, and refining and the mill recovery of 90% of copper contained in the ore and smelter/refinery recovery of 95% of the copper contained in the concentrate. Ore reserves total 476 million tons, limiting mine production life to 24 years at the operating rate of 6 thousand tons of ore per day. There are also assumptions about allowed depreciation, depletion and tax rate reflected in the tax bill. The company considers 15% to be a minimum acceptable return on investments; a return below that level indicates that there are probably better uses for their capital. The cash flow pattern shown has a present value of $61.8 million at a 15% discount rate and a discounted cash flow rate of return of 20.5%.

THE PROBLEMS

The problems arise from the need to make technical and economic forecasts over the future life of the mine. The technical assumptions can be described as the "design basis" for costing and performance. to these are added the economic assumptions, the most critical being future prices and the rate of escalation of future prices and costs. The industry has responded to these forecasting problems with "standard" approaches seem to work most of the time with time out for a number of disastrous errors. To illustrate, a number of risks are reflected in the copper mine cash flow model.

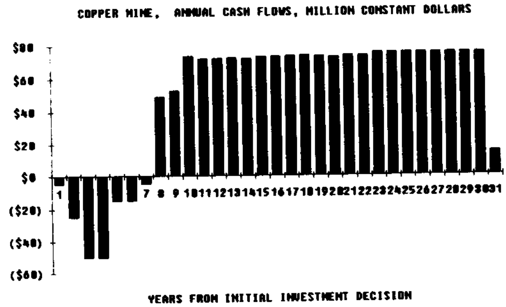

Fig. 1 Copper Mine Cash Flows

Design Basis

Two RAND studies deal with cost estimation in new technologies and attempt to explain cost growth and performance shortfalls in process plants (Merrow, 1979,1981). They seek a better understanding of the reasons for inaccurate estimates of capital costs and performance difficulties for first-of-a-kind process plants,especially energy process plants. The conclusions of the study are very much relevant to the mining and processing of ores because of the unique and"pioneer" nature of the mining investment. Ore bodies are unique and have many of the characteristics of a pioneer investment.

The RAND study conclusions identify reasons why the pioneer process plants often understate capital costs by more than 100%. Unexpected inflation, government regulation, weather and project management play a role in explaining cost growth but the major culprits are changes in the design basis - those changes in project scope, size, and design that come about as the uncertainties of a preliminary estimate become realities. The fact is, the final plant is very different than the one modeled for the earlier investment decision. This derives from the use of uncertain, and unproven "innovative" technology and the lack of project definition when investors decide to proceed with major expenditures. The operating side of the same problem is found in the survey of start-up performance. the usual assumption is 80-85% of nameplate capacity after 6 months. The plants surveyed by Rand experienced an average 49% of design capacity after 6 months and only 2 of 15 operated at 85% of capacity in months 7-12.

The experienced engineer is familiar with many cases of design basis and low performance problems on mining projects. These include the impact of investment timing and cost overruns, delays in start-up, lower than expected rates of production, higher than expected mine, mill, smelter or refinery operating costs, lower than expected metallurgical recoveries, errors in estimating recoverable ore grade, and all the other impacts on projects value due to the "design basis" errors. The cash flow model serves to illustrate the impact of these on net present value (NPV) and the discounted cash flow rate of return (DCFROR) of the project. All references to NPV are to a value calculated at the 15% discount rate.

Investment Cost Overrun: Assume that the actual size of the investment in the model copper mine turns out to be 20% higher than forecast. The overrun is explained as follows: (1) due to equipment deliveries behind schedule and unexpected price inflation because of a crisis in the mid-East, (2) the oxide leach operations produced an unsatisfactory cement copper product requiring installation of drying and pelletizing facilities, (3) ground conditions were different than expected - instability in the open pit slopes required redesign of the haulage system and unexpected additional stripping of the orbed, (4) certain crushing and grinding equipment failed to perform as expected and had to be replaced, (5) financing of the project required delivery of equipment from sources more distant than expected resulting in delays and additional ocean freight, (6) the scope of support infrastructure was expanded to meet government requests, (7) working capital exceeded estimates because of larger then expected inventories of product. For every 1% increase in the total investment the net present value declines $1 million, a strong effect due to the larger negative cash flows at the beginning of the project. The overrun reduces the NPV by $20.1 million to $41.7 million and the DCFROR to 18.3%.

Mill Recovery: Assume a second problem is found in the metallurgical recovery in the mill. The actual value turns out to be 85% reflecting the effect of refractory ores. The recoveries affect revenues over the life of the project and compound the error of the investment cost overrun, reducing the NPV to $19.5 million and the DCFROR to 16.6%. Management explains the difference as a result of scale-up error in projecting the results of small scale metallurgical tests. Critics say that there should have been pilot plant testing prior to commitment to construction of the mill.

Ore Grade Estimates: Assume still another problem. In two drilling campaigns, the company drilled 2000 holes in the ore body, using a reverse circulation down-the-hole hammer method. The method was necessitated because of extensive old underground workings which were caved or back-filled.

Ore reserves were first calculated in using the polygonal and manual cross section methods. These were followed by inverse distance methods, a more sophisticated geostatistical approach using variograms to determine the range of influence for each hole. This range turned out to be less than the drill hole spacing. The new information indicated that reserves were shaky.

The polygonal method resulted in an estimate of reserves of 500 million tons with an average grade of 0.8% copper. the inverse distance method resulted in an estimate of 450 million tons with an average grade of 0.6% copper. This raised the question of whether to use the polygonal result, the inverse distance result or an average of the two for economic evaluation. A third geostatistical study came close to the average of the polygonal and inverse distance methods so the average became the basis for evaluation, hence the assumption of 476 million tons of ore averaging 0.7% copper.

Unfortunately, after operations were underway it became clear that the inverse distance estimate was the correct one. As a result the actual geologic ore reserve dropped by 632,000 tons of copper. The combination of lower metallurgical recovery and the mis-estimate of ore grade meant that 703,880 tons of copper, $1.3 billion in revenues would not be available to support the economics of the operation. In terms of the cash flow model, two years of ore production and 0.1% lower grade reduced the NPV of the project to a negative $34.9 million, indicating that the rate of return was below the 15% minimum acceptable rate of the company. Nevertheless the NPV of the project was still a positive $24.6 million at the 10%

discount rate, and since the investment was a sunk cost, there was little alternative except to proceed and hope for better prices than those used in the evaluation.

Cost Estimation

In this hypothetical cash flow model we assume that capital and operating costs were estimated with such accuracy that the true value of the project was unaffected by this source of error. This assumption is likely to be far from the truth if the evaluation is made using factored techniques and incomplete data. Contingency factors for preliminary estimates are often 20% to 30% in these early estimates and the RAND studies indicate that they uncertainty may warrant factors closer to 100%.

The impact of error in capital cost has been demonstrated. In the operating cost area the impact on value is proportional the contribution to total cost of each component. In the copper model the relationship of cost components is shown in figure 2.

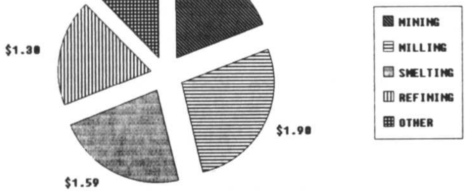

Fig. 2 Distribution of Total Cost in the Copper Model

In this model there is a fairly even distribution over all components. The open pit mining cost puts this component in balance with milling, smelting, and refining. If the operation was from a relatively high cost underground mining method, it is possible that this component would dominate the economics. Errors in estimating the cost of energy, steel, or manpower could cause dramatic effects on the economics of the processing components.

If the smelting and refining are not controllable by the mining company then errors and trade-offs between mining and milling will dominate the analysis, with the objective a minimum total cost of production. The "other" category includes overhead, freight, property and severance taxes, strike expense, and royalties. Environmental expense and equipment replacement costs are not included but are accounted for separate as capital expenditures recovered through depreciation. Allocation of overhead costs may allow for flexibility if the project is operating close to break-even.

Given the shock of prior changes in the design basis, the need for a precise estimate of operating cost is clear. If operating cost were to average $7.50 per ton of ore rather than $7.00 the NPV of the investment would be a negative $7.9 million at the 10% discount rate... 68% of the remaining value would be lost. And the DCFROR would be a non-competitive 9.5%.

Major sources of potential cost savings or problems can be identified if the contributors to cost are identified. For example, in the copper model figure 3 identifies the costs of labor and supervision, crushing and grinding steel, and electric energy as the largest components. Changes in the design basis may trade-off some of these expenses for changes in mining, smelting or refining costs. Changes in the pricing of these input requirements also will affect NPV of the project.

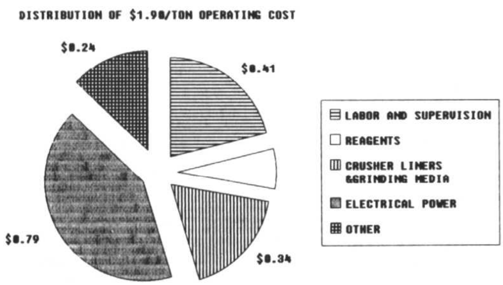

Fig. 3 Distribution of Milling Cost in the Copper Model

Markets - Price Forecasting

The final variable considered here is the most difficult of all to forecast and likely to have the most dramatic effect on the NPV of the investment. The volatile copper price directly affects NPV through revenues. In the original model a change of one cent in copper price causes the NPV to change by $4 million. As other problems become apparent the present value becomes smaller and the $4 million loss or gain becomes even more critical.

Initially, the $1.00 constant dollar price assumption of the copper model appears reasonable in view of the $1.30/lb. average historical price of copper over the period 1900 to 1988. But it is the price cycles that confound the forecaster. Over the most recent decade the average has slipped to $0.90/lb. Shorter term swings are even more volatile. This uncertainty leads forecasters to prefer price range forecasts such as the one shown in figure 4.

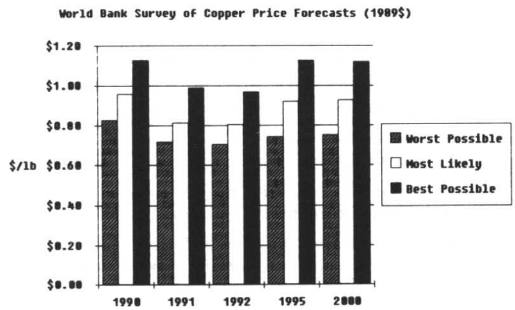

Fig. 4 World Bank Survey of Copper Price Forecasts ($1989)

The price forecasts shown are based on the published results of a survey by the International Economics Department of the World Bank. The survey was conducted along the lines of an opinion poll of industry and government forecasters who were asked for their estimate of the worst possible price, the most likely price and the best possible price for copper at the points in time indicated.

The World Bank survey undoubtedly includes input from all four principal forecasting techniques:

(1) Qualitative methods rely on judgements based on experience and information available to the forecaster. It is the most commonly used approach.

(2) Cost and reserve based methods rely on the idea that, over the long term, price will move toward the cost of