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FINANCIAL EVALUATION OF MINERAL INDUSTRY CAPITAL PROJECTS

by

Harry Joseph Winters, Jr.

A Dissertation Submitted to the Faculty of the DEPARTMENT OF MINING AND GEOLOGICAL ENGINEERING

In Partial Fulfillment of the Requirements For the Degree of DOCTOR OF PHILOSOPHY WITH A MAJOR IN GEOLOGICAL ENGINEERING

In the Graduate College

THE UNIVERSITY OF ARIZONA

1972
I hereby recommend that this dissertation prepared under my direction by Harry Joseph Winters, Jr. entitled Financial Evaluation of Mineral Industry Capital Projects be accepted as fulfilling the dissertation requirement of the degree of Doctor of Philosophy.

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PREFACE

There are a number of very difficult questions which come up time and again in the financial analysis of mining and exploration projects. These questions range all the way from the very basic one of deciding what is a satisfactory profitability measure for mining projects to all the very diverse questions involved in measuring the costs and benefits of projects.

It is the objective of this dissertation to develop answers to a number of these questions. In this manner, a framework for evaluation of mining and exploration projects is developed.

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ABSTRACT

There are many methods of selection and ranking of mineral industry capital projects for investment purposes in use by mining companies, commercial banks, and investment banking houses. On the surface, many of these methods do not seem to be in agreement with the logic of discounted cash flow methods of capital budgeting. The discounted cash flow methods include use of net present value and discounted cash flow return on investment. However, careful analysis shows that substantial areas of agreement can be found between discounted cash flow criteria and such other criteria as contribution to earnings per share, position of production cost in world production cost ranges, and policies of rejection of small ore deposits.

Analysis of risk in mining investments shows that risk usually has its origin in geology or in the personnel involved in the project. The degree of variation to which the profitability of a project may be subject is best determined by sensitivity analysis. Use of risk-adjusted discount rates is not a good procedure. It may lead to neglect to give sufficient thought to programs which could be undertaken to remove risk from a project. It may also lead to rejection of projects with very good profit potential.

Mineral exploration policy can be established on a rational basis by classification of ore bodies of mineral commodities of interest into a small number of types based on their mining and metallurgical economics. Profitability analysis of the various classes of ore bodies
then provides exploration management with reliable information as to what kinds of ore bodies can meet their company's investment standards.

Once an exploration target is found, sensitivity analysis and discounted cash flow analysis can be used together to determine the sequence of activities which will provide the information most urgently needed for prospect evaluation.

In feasibility studies of new mining ventures particular attention should be paid to proposed production schedules and any assumptions in them on selective mining. Analyses of possible contributions to profits of byproducts and coproducts should be based on a knowledge of their actual distribution in the ore body rather than on averages over the ore body. Allowances must be made for learning period costs in the early years of life of new mines.

Selling prices of products of new mines for use in feasibility studies should be conservative prices for the year in which the mine will commence production. If prices are not assumed to rise in the study over the mine's life, operating costs should not be assumed to rise either.
PROJECT SELECTION CRITERIA AND POLICIES

Advocates of the discounted cash flow (DCF) methods, net present value (NPV), and return on investment (DCFROI) of ranking and selection of capital projects frequently criticize non-DCF criteria of investment valuation. The texts of Quirin (1967), Bierman and Smidt (1966), and Johnson (1966) contain many examples of such criticism. The non-DCF criteria subjected to such criticism include the impact of a project on earnings per share, the payback period, criteria referred to as "accounting rates of return," and others. Of course, this criticism flows both ways, but the validity of the DCF techniques, when carefully used, has been so well established as to require no defense (Quirin, 1967; Bierman and Smidt, 1966). The validity of these methods is a basic assumption of this dissertation.

In spite of the clearly demonstrable validity of DCF techniques, executives of highly successful mining companies, commercial banks, and investment banking firms frequently place little or no weight on DCF techniques in evaluation of mining projects. They often rely instead on the very techniques which proponents of DCF methods criticize and which, in fact, do lack important characteristics of valid project selection criteria. They also adhere to certain investment policies which upon cursory consideration seem to be in conflict with the logic of DCF methods.

The purpose of this chapter is to compare certain non-DCF project selection criteria and policies with the DCF criteria and to
demonstrate the degree to which the two sets of valuation rules may be reconcilable.

The success of the men who rely on non-DCF methods makes it reasonable to expect to find elements of real consistency between their reasoning and the valid thought behind the DCF methods. Recognition of areas of consistency provides one with a number of viewpoints from which to examine proposed investments. This kind of insight can contribute substantially to sound investment decisions.

**Earnings Per Share**

The impact of a proposed investment on earnings per share of common stock is a widely used measure for the value of an investment. For a large part of the United States' financial community, including many boards of directors, it is the most important indicator of the worth of an investment (Dohr et al., 1964, p. 125-27; Stern, 1970, p. 107). The contribution of a project to earnings per share is computed by dividing the income a project will make available to common stockholders by the number of shares of common stock outstanding.

Dohr et al. (1964, p. 124-126) discuss the importance of earnings per share in a very convincing manner. A shareholder is interested more in the return on his own investment than in the company's return on its investment. Earnings per share is a measure which may be projected into the future and which provides an investor with information on the outlook for return on his investment. Future earnings will be a prime determinant of capability of the company to pay dividends and of possibilities of capital gains to be realized upon sale of shares.
Mining company executives usually mention no criteria of investment worth other than contribution to earnings when they make statements for publication about new mining projects. Howard Boyd (Forbes, 1969, p. 24), chairman of the board of El Paso Natural Gas Company, in an interview discussed the Lakeshore, Arizona, copper project. El Paso owns a 50 percent interest in profits of this new mine which is scheduled to commence production in 1973. Boyd estimated that "by 1983, El Paso's 50% interest in the profits will add $14 million in pre-tax profits to El Paso annually--probably 25 cents or more a share after taxes." Boyd did not mention any other profitability criterion.

An article on the Sagasca, Chile, copper project of Continental Copper and Steel, Inc. was published in Forbes, 1970, p. 19). The article is apparently based on an interview with M. S. Gordon, chairman of Continental Copper and Steel, Inc., since he is quoted extensively. The article states: "... Sagasca will have a dramatic impact on Continental earnings when it goes into production a year from now. As against the 56 cents a share the whole company earned last year, and with not much more in prospect for 1971, Sagasca would contribute $1 a share with copper at 42 cents a pound, $2 a share with copper at 60 cents." No other profitability criterion is mentioned in the article.

As an example of the use of contribution to earnings as a valuation criterion in the mining industry, C. O. Ensign (1969), president of Copper Range Company said in 1969 that his company desired that a new mining operation contribute to after-tax earnings a minimum of about $0.20 per share of common stock outstanding. "Based upon
approximately 2,000,000 shares of our common stock outstanding, the smallest size of new venture Copper Range would consider must be capable of generating additional earnings of about $400,000 per year" (Ensign, 1969, p. 16). Assuming an effective income tax rate of 50 percent, pre-tax income would have to be $800,000 per year. Many relatively small ore bodies would support a mining operation capable of fulfilling this requirement.

Ensign (1969, p. 17) points out that this is not a rigid guideline, but "one form of aid for our staff." Copper Range also uses the DCFROI and payback period criteria.

There are serious objections to the use of contribution to earnings per share as a project selection criterion. The accounting concept of income which is reflected in earnings per share is subject to all the nuances of accrual accounting systems of measurement of income and is thus inadequate for investment analysis. Problems arise in accounting for inventory, depreciation, depletion, and other reserves. The recording of a sale or cost in a particular year does not indicate that a cash benefit is received or cash outlay made in that year. Bierman and Smidt (1966, p. 106-108) present a good discussion of this matter. They state:

The use of earnings to measure the benefits of an investment would require a much more sophisticated theoretical accounting system than is currently being used by any corporation. The earnings figures resulting from current accounting practices are not usable. Also, even with improved measures of income, there would remain the question as to whether the use of cash flows or earnings is more appropriate. The advantage of the use of the cash flow is that the receipt of cash is an objective, clearly defined event that leads to a significantly different situation than before the receipt of cash.
A company may calculate cash earnings per share, which is an objective measure, but this still does not overcome the following objection. Use of earnings per share, whether on an accrual or cash basis, does not recognize the time value of money. Earnings in one time period are given the same weight as earnings in other periods. Recognition of the time value of money is one of the basic tests of validity of a project selection criterion.

Since earnings per share is calculated on a post-interest basis, valuation of the earning power of the assets under study may become confused with financing problems.

These considerations lead to the question of why officers and directors of many highly successful companies repeatedly involved in analysis of mineral industry projects place heavy, frequently predominant, weight on this profitability measure.

The principal reason for the popularity of contribution to earnings per share as a project selection criterion is that management is well aware of the association between the outlook for earnings per share and share prices and between share prices and the cost of capital, both equity and debt, to the firm. If the outlook for growth of earnings is good, share prices should be high, and shareholders generally consider that management is fulfilling its responsibility to maximize their wealth.

In this environment, the potential contribution of a project to earnings per share becomes the sine qua non of the investment value of the project. This seemingly reasonable attitude on the part of corporate management can be reconciled to a significant degree with the reasoning underlying the DCF methods.
The cost of capital to a firm, which for the profit-maximizing firm is the discount rate in computing NPV and against which the DCFROI must be compared, is a function of the outlook for earnings per share over a period of future years. This relationship is the basis of the reconciliation sought. Solomon (1956) has captured the relationship between earnings and cost of capital in his model of a company's cost of capital, which may be written:

\[ k = \frac{E_a}{P} \]

with \( k \) the cost of equity capital, \( E_a \) the expected average future earnings per share, and \( P \) the amount which would be realized from sale of a share.

Gordon and Shapiro (1956) have also captured this concept in their model of a company's cost of equity capital. Their model is written:

\[ k = \frac{D}{P} + g \]

with \( k \) the cost of equity capital, \( D \) the current dividend, \( P \) the amount which would be realized from sale of a share, and \( g \) the expected average growth rate of dividends.

The above models indicate that the cost of equity capital cannot be properly estimated without first estimating the impact of a project on earnings per share and without considering the effects of possible changes in earnings or changes in outlook for earnings on share prices. The amount of money available to pay out as dividends generally depends on the size of earnings.

Ignoring short-run effects of publicity, a project which will make an insignificant contribution to earnings will not cause a rise in
share prices. Some small mining projects may offer a high DCFROI but only a very small contribution to the earnings of a corporation with tens of millions of shares outstanding. This is true, for example, of some small copper projects based on heap leaching of small reserves of oxide copper or mixed oxide-sulfide ores. Such a project may yield a DCFROI of 20 percent or more but may produce only $0.02 to $0.04 cash flow per share to a corporation with tens of millions of shares outstanding. An example of such a situation is discussed later in this chapter.

If shareholders anticipate that a new project will jeopardize earnings or dividends over a period of time too long to their liking and as a result sell their shares in a market with mediocre demand for them, the firm's cost of equity capital will rise. This means that the NPV of the project will be lower.

The compatibility of the earnings-per-share criterion and the DCF methods can be demonstrated in analytical form by using an approach developed by Gordon (1963). He pointed out on the bases that "(i) investors have an aversion to risk or uncertainty, and (ii), given the riskiness of a corporation, the uncertainty of a dividend it is expected to pay increases with the time in the future of the dividend, . . . an investor may be represented as discounting the dividend expected in period \( t \) at a rate of \( k_t \)," with \( k_t > k_{t-1} \). Gordon's model of the value of a share is then

\[
P_0 = \frac{y_0}{(1 + k_1)^1} + \frac{y_0}{(1 + k_2)^2} + \cdots + \frac{y_0}{(1 + k_t)^t}
\]

with \( P_0 \) the present value of a single share, \( y_0 \) the dividend, and \( k_t \) the discount rate in period \( t \). It does not matter for this analysis that \( y_0 \) is held constant.
As an example, assuming that an investor's required rate of return is seven percent and that he attaches a risk premium of one percent to dividends receivable in year two and two percent in year three, that the company will cease paying dividends after year three and the shares will be worthless, and that the yearly dividend is $1.00 per share, then the price of a share would be:

\[
P_0 = \frac{$1.00}{(1 + .07)^1} + \frac{$1.00}{(1 + .08)^2} + \frac{$1.00}{(1 + .09)^3}
\]

\[
P_0 = $2.56.
\]

This type of analysis only indicates the possible impact on share prices of uncertainty about future earnings and dividends, and an analyst would be rather naive to think that accurate share prices are actually determinable in this manner.

In the light of Gordon's model, the cost of equity capital may be thought of as an "average" of the \( k_t \). If stockholders believe that acceptance of a mining project involves a real chance of deterioration of earnings or dividends, the cost of equity capital will probably rise. This means that the minimum acceptable DCFROI will be higher than a cutoff DCFROI estimated by dividing expected average earnings by current share price. The possible impact of a project on earnings per share in both the preproduction and production periods must be estimated and studied to arrive at the most reasonable value of the cost of capital.

Thus, when Ensign (1969) of Copper Range Company points out the importance of the contribution of a project to earnings per share, he is giving recognition to the relationship between earnings and his firm's cost of capital. This is the basis of reconciliation of the attitude
of corporate management toward earnings per share with the logic behind DCF analysis.

The opposition of Golconda Mining Corporation to Hecla Mining Company's participation in the Lakeshore copper project in Arizona provides an informative example of one reaction of a shareholder to possible changes in earnings due to undertaking large mining projects.

At the end of 1968, Golconda owned 12.4 percent of the outstanding shares of Hecla. In 1966, dividends from Hecla gave Golconda $365,655 of its $401,927 income; in 1967, $389,790 of $401,628 income; and in 1968, $427,980 of $444,728 income.

On February 11, 1969, Hecla's Board of Directors, with one dissenting vote, approved the acquisition of substantially all the assets of Transarizona Resources, Inc., a subsidiary of El Paso Natural Gas Company, including an undivided one-half interest in the Lakeshore properties for 1,000,000 shares of the authorized but unissued capital stock of Hecla. This transaction would raise the number of outstanding shares of Hecla stock from 4,957,575 shares to 5,957,575 shares, a substantial dilution. In addition, Hecla was required to pay $1,500,000 to El Paso in order to acquire El Paso's undivided one-half interest in a mill on the property. Hecla was required to provide all financing and have sole risk and responsibility for bringing the property into production. The cost of development could ultimately approximate $100,000,000 according to 1969 estimates (Hecla Mining Company, 1969). Hecla is proceeding with the development of a part of the ore body, which development is to be completed in 1973. Hecla was to make advance minimum royalty payments to El Paso of $250,000 quarterly, beginning in the
fifth calendar quarter of the agreement. El Paso is entitled to 50 percent of "net profits," defined as gross income before income taxes less operating costs and less an annual charge of 10 percent of preproduction costs over a period of ten years and less any accumulated prior losses. Hecla has the right to recoup out of El Paso's share of net profits all minimum advance royalties and accrued interest on 50 percent of the un-amortized balance of preproduction costs at an annual rate of 3.5 percent (Hecla Mining Company, 1969).

The dissenting vote at the Hecla board meeting was that of H. F. Magnuson, then a vice president and director of Golconda. On February 12, 1969, the officers of Golconda issued a statement expressing opposition to the proposed transaction between Hecla and El Paso and Transarizona. Golconda contended that the investment would mean decreased earnings per share for the next five years, launched a proxy fight against the venture, and filed suit in the U.S. District Court in Spokane, Washington, to block the transaction.

Golconda lost the proxy fight when Hecla's shareholders approved the agreement on May 29, 1969, and Mr. Magnuson was not reelected to Hecla's Board of Directors. The suit instituted by Golconda did not succeed.

Hecla paid a dividend of $0.17 per share in 1970 down from $0.69 in 1969 and $0.65 in 1968. Hecla's earnings per share were $0.78 in 1970, $0.80 in 1969, and $0.76 in 1968 (Hecla Mining Company, 1971a). These earnings figures reflect a two percent stock dividend paid by Hecla on August 1, 1970. "The stock dividend paid in 1970 assisted in conserving funds needed for financing preproduction costs at
the Company's Lakeshore Arizona copper property" (Hecla Mining Com-
pany, 1971b).

If a project offers a substantial increase in earnings per share
with very little risk to earnings or dividend-paying capabilities during
the preproduction interval and payback period, a company should exper-
ience no adverse effects on its cost of equity capital by undertaking the
project. It should experience beneficial effects.

However, there are circumstances which are not uncommon in
mining investments which could lead shareholders and security analysts
to look askance at such investments. The long periods of time required
for the development of many new mines or mine expansion projects, the
number of years required for payback of investment, the huge capital
requirements for development and construction, and the common and
large cost overruns could give rise to situations in which the dividend-
paying capabilities of mining firms could be jeopardized or impaired.
Anticipation of such situations might lead to a decline in share prices.

Peters (n.d.) has prepared a very comprehensive study of the
preproduction interval at new mines. He defines the preproduction inter-
val as "the time between recognition of the best potential of the ore body
and the beginning of significant ore shipment" (p. 5). He finds that the
majority of new mines have preproduction intervals of two to five years
and that "many of the large-scale mines with low unit value ore and com-
plex processing or marketing" (p. 6) have preproduction intervals of five
to seven years. Some mines "characterized by difficult physical condi-
tions, large technologic problems and complex economic problems"
Mines which require over seven years to bring into production. Mines which require two years or less are characterized by "near-optimum physical conditions" (p. 6).

The terms of loans for the huge sums of money required for new mines may potentially or actually impair a company's ability to pay dividends for a period of years. This is particularly true if a surplus of the mineral commodity develops for even a relatively short period or if a company is deriving a significant portion of current earnings from operations in areas of political or social unrest. Loss of earnings from other sources coupled with the capital requirements of projects under development could cause reduction of dividends for some time.

Costs of development and construction at new mines and expansions of existing mines have far exceeded original estimates based on feasibility studies in recent years. These overruns are due largely to two factors. First, inflation has sent costs of materials and labor soaring. It is not unusual to find costs of development tasks rising at a rate of six or eight percent per year. Second, ore bodies are being developed which are frequently much more difficult to sample and which are of more difficult metallurgy than ore bodies of earlier years. As block caving and other underground mining methods reassume their importance in the United States and as surface mines become deeper, engineers must develop more thorough understanding of the effects of geologic structures and rock pressures on amenability of ore bodies to mining. The following are good examples of the type of cost overruns being experienced.
At a meeting of the Board of Directors of Newmont Mining Corporation on October 29, 1970, its president, Plato Malozemoff, announced that Magma Copper Company's expansion program at San Manuel and Superior, both in Arizona, was expected to cost in excess of $250,000,000. The revised figure, some $100,000,000 more than earlier estimates, represented greater than anticipated increases in construction costs and additions made to the project after it was underway (Pay Dirt, 1970, p. 22). In Newmont's annual report for 1969 (Newmont Mining Corporation, 1970, p. 4, an expected cost of $160,000,000 had been published. According to Malozemoff (Pay Dirt, 1970, p. 22), expenditure for the program is so large that Magma was borrowing about $60,000,000 in addition to about $20,000,000 it already had borrowed from the Prudential Insurance Company. Malozemoff expected the company would also have to borrow between $40,000,000 and $60,000,000 in additional capital.

A proxy statement issued in March 1969 by Newmont Mining Corporation, one of the four shareholders in Southern Peru Copper Corporation, contained the following information on Southern Peru's Cuajone copper deposit. "The overall cost of the Cuajone project was estimated as of mid-1968 at $335,000,000, including interest during construction, mine preparation, a 30,000-ton per day mill, 17 miles of railroad tunnels, facilities for employees and enlargement of the Ilo smelter" (Newmont Mining Corporation, 1969, p. 32). It was expected that it would take approximately five years after an agreement had been reached with the government of Peru to place Cuajone into production.
One year later, American Smelting and Refining Company, another shareholder in Southern Peru Copper Corporation, informed its stockholders that as of mid-1969 costs of the project had been reestimated at $355,000,000 (American Smelting and Refining Company, 1970). The same company in the first half of 1971 stated that negotiations were underway with a group of Japanese and European companies for the financing of the Cuajone project which by then was estimated to cost more than $400,000,000 (American Smelting and Refining Company, 1971).

On June 18, 1970, N. A. Kindwall, treasurer of Freeport Sulphur Company, told the Pinnacle Club in New York City that the total required funds for his company's Ertsberg copper project in West Irian, Indonesia, would be $120,000,000. Anticipating possible cost overruns, Freeport arranged that each of the basic loan and equity commitments be subject to increase on a pro rata basis to the extent of 20 percent of the respective commitments. In its 1970 annual report to the shareholders, dated February 24, 1971, Freeport's management announced that the estimated cost of the Ertsberg project had been revised to $135,000,000.

These examples should be sufficient to show that there are features of certain mining investments, such as long preproduction and payback periods and possibilities of large development and construction cost overruns, which may pose a potential threat to earnings or to ability to pay dividends. The possible impact on share prices of expectations of shareholders that such characteristics will actually jeopardize a
company's earnings must be taken into account in analysis of a mining project.

It can be concluded that, although contribution to earnings per share is not by itself an adequate project ranking or selection criterion, it is very important to calculate it since an accurate estimate of the firm's long-run future cost of capital cannot be made without first estimating future earnings. There is no essential conflict between the use of earnings per share and DCF project selection criteria. The first supports the second. One should not be used without the other.

**Rejection of Projects with Short Lives**

Many large mining companies reject possible new mining projects with short lives but high DCFROI's in favor of exploration or development of deposits with longer lives even though they may have lower DCFROI's. This is particularly true when these companies are in capital rationing situations, but it often holds true even when they are not in such situations.

In its annual report to its shareholders for 1968, Cerro Corporation (1969, p. 9) announced that it had acquired a 53.3 percent interest in Big Mike Corporation, together with a 60 percent interest in a joint venture with that company, which held a copper deposit located near Winnemucca, Nevada. The deposit was estimated to contain about 600,000 tons of sulfide and oxide mineralization averaging 4.5 percent copper. Cerro was undertaking a feasibility study on mining the deposit.

In December 1969, Ranchers Exploration and Development Corporation acquired all of the assets of Big Mike Corporation in exchange for
30,000 shares of common stock and repayment of $92,000 in outstanding debentures which had been issued by Big Mike. An additional 7,170 shares were issued in exchange for the interest of Cerro in its joint venture with Big Mike (Ranchers Exploration and Development Corporation, 1970, p. 2). Cerro received a total of 23,170 shares in the transaction which represented 3.03 percent of Ranchers' outstanding shares. Cerro and Ranchers entered into a joint venture for the further exploration and possible development of an area outside the limits of the known mineralized zone. According to Ranchers (1970, p. 12), Cerro transferred its interest to Ranchers "due to other pressing commitments."

Cerro had 7,362,000 shares of capital stock outstanding in 1968 and 7,758,000 shares in 1969. Earnings per share were $4.01 in 1968 and $5.04 in 1969. Cash dividends of $1.45 were paid in 1968 and $1.52 in 1969. A five percent stock dividend was declared in both years.

Ranchers had 626,856 shares of common stock outstanding in its fiscal year ending June 30, 1968 and 737,808 shares in its fiscal year 1969. Earnings per share in fiscal 1968 were $1.11 after extraordinary items in 1968 ($0.69 before such items), and $0.99 in fiscal 1969. The company paid no dividends in 1968 nor in the three preceding years.

As of March 31, 1970 (Ranchers Exploration and Development Corporation, 1970, p. 4), ore reserves at the Big Mike mine were estimated as follows:

<table>
<thead>
<tr>
<th>Ore Zone</th>
<th>Tons Ore</th>
<th>% Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed oxide-sulfide</td>
<td>644,250</td>
<td>2.21</td>
</tr>
<tr>
<td>Massive sulfide</td>
<td>129,450</td>
<td>10.18</td>
</tr>
</tbody>
</table>
Ranchers had a contractor begin stripping in January 1970. By May 1970, mining of the massive sulfide ore was underway at a rate of 1,500 to 2,000 tons per day. Only the massive sulfide was mined in the first stage of operations. Ore was crushed to minus 1 1/2 inch and shipped direct by truck, rail, and ocean-going vessels to smelters in Germany, Spain, and Sweden. By September 15, 1970, Ranchers had suspended operations, having shipped 95,000 tons of high-grade ore with a gross value of $11,200,000. In addition, 3,200,000 tons of waste had been stripped, 275,000 tons of lower grade ores had been stockpiled, and drilling had blocked out over 400,000 tons of oxide-sulfide ore (Nevada Mining Assoc. News Letter, April 15, 1971, p. 2).

As of April 30, 1970, Ranchers had spent $1,666,461 at the Big Mike mine. Of $5,000,000 borrowed by Ranchers on April 9, 1970, $4,000,000 had been or was to be used to cover mining and shipment costs of the high-grade massive sulfide ores (Ranchers Exploration and Development Corporation, 1970, p. 4 and 18).

This was a mining project of short life but high DCFROI. Even when the mining and treatment of the lower grade ores were taken into consideration, it was not anticipated that the life of the mine would be more than about five years (Nevada Mining Assoc. News Letter, Oct. 15, 1969, p. 1).

Cerro Corporation, a large corporation, apparently in a capital rationing situation, sold its interest in the deposit to a small corporation to which such a deposit, even though of short life, could be very important.
A financial officer of an important domestic mining company recently told the writer that his company would want a relatively high return on investment, for example, 18 percent to 20 percent, from a project with a life of less than 10 years. On the other hand, if a project would have a life of 30 to 50 years, the company would probably accept a 10 percent return on investment.

One may ask if Cerro's action was a reasonable action for a firm which wishes to maximize profits. One may further ask if its action does not run counter to investment policy indicated by DCF methods. Similar questions may arise with regard to the attitude expressed by the second large domestic company. In the author's opinion the action of Cerro and the attitude of the second corporation are both rational and not contradictory to investment policy indicated by DCF methods.

The principal reason for this opinion rests on the reinvestment assumptions implicit in use of DCF methods of ranking projects and on the size distribution of ore deposits.

Quirin (1967, p. 82-84) presents a good discussion of the reinvestment assumptions. Given two projects, one offering an 18 percent DCFROI with a life of 3 years and the other offering a 12 percent DCFROI with a life of 20 years, if a firm selects the project with the higher DCFROI, management implicitly assumes that by the end of life of the project there will be an opportunity for reinvestment of the funds at a DCFROI at least as high as that of the project with the longer life. If such an opportunity does not await the firm, its long-run profitability would be better served by selection of the project with the longer life in spite of its lower return. As Solomon (1956) has said, "The ultimate
criterion is the total wealth that the investor can expect from each alternative by the terminal date of the longer lived project."

Faced with such a situation the management of a mining company must consider how probable it is that its exploration staff will discover a whole series of small deposits offering a return on investment higher than the return the company would earn on the 20-year project.

Exploration efforts in the last two decades have demonstrated that the chances of finding small, highly profitable deposits in the United States are not much better than the chances of finding a large deposit with lower but still satisfactory profitability. The chances of finding new deposits are, of course, determined to a degree by the thoroughness with which an area has been prospected. A large number of small but very reasonably profitable uranium deposits were found and operated during the 1950's in the western United States, an area which previously had been thoroughly prospected for other metals, but not for uranium. It will be a rare mining company which will find itself faced with a series of projects with short lives in which it can continue to reinvest, thereby consistently earning a higher return on investment than would be obtained by investing a larger sum of money in one or two projects with longer lives but somewhat lower returns on investment.

Foreknowledge of this situation should influence a firm's exploration policy as well as its policy of investment in new mines. The long-run profitability of a firm in many instances will not be well served by spending exploration manpower and dollars in the search for small deposits with low investment requirements and the siren promise of an exceptionally high return on investment.
A second and extremely important argument supporting the reasonableness of large company management's attitude toward small deposits springs from management's comprehension of the strong relationship between the outlook for earnings and dividends in the eyes of security analysts and shareholders and the firm's cost of capital. If a firm has secure, long-run earning power based on large tonnages of ore reserves, the risk involved in holding the firm's shares should be lower than if the firm has invested only in small projects with lives of a few years. This is true even though the small projects may offer a relatively high return on investment. This implies that the firm's cost of equity capital will tend to be held down more by investments in projects with long lives than by investments in projects with short lives, even though the return on investment in the smaller projects may be somewhat higher than the return on investment in a large project.

A third argument supporting rejection of these projects by many companies is that they require the time and attention of executives, just as larger projects do, if they are to achieve the potentially high profitability which they promise. The cost of executives' time is an opportunity cost. It is not a portion of their salaries, but the profits they might have generated over future years had their time been spent on other projects, which represent the true cost of their time.

Since few people can work efficiently, and fewer can think creatively, when they must divide their time among a host of activities, this argument has considerable merit. An excellent discussion of this argument has been presented by Jones (1968).
A fourth reason for being wary of projects with short lives is the risk involved in the prices of many mineral commodities. A number of mineral commodities are subject to violent short-run price fluctuations. A significant drop in the price of a mine's product over two years of the life of a mine with a five- or six-year life can seriously lower the return on investment. If prices fall, many mines can be closed for a period of time, but some will incur costs even while closed. It may be necessary to maintain timber and continue pumping water from underground mine workings even when the mine is closed. Either the staff that has been gathered must be paid, or it must be let go, and the cost of recruiting a new staff incurred when it is possible to reopen the mine. A great deal of money may have been spent developing reserves which will not be mined until a year or two after they were scheduled for production. Postponement of commencement of payback for a year or two can seriously lower the return on investment.

In the summer of 1970, U.S.N.R. Mining and Minerals, Inc. commenced production from a small oxide copper deposit in New Mexico. Ore reserves, which occur in two small deposits, were estimated at 16,000,000 tons with a possible additional 4,000,000 tons. The average grade of the reserves was estimated at 0.52 percent copper and approximately 50 percent of this copper was assumed to be recoverable by heap leaching over a 9-year period.

At the time U.S.N.R. Mining and Minerals, Inc. decided to bring the property into production, the price of cement copper was very high, and the company was able to sell 13 million pounds in advance at a price of 52¢ per pound of copper in cement form. One estimate
of the cost of production of cement copper from the deposit was 37.7¢ per pound, including New Mexico taxes, royalties, depreciation, and depletion. Today the selling price of cement copper is less than 40¢ per pound. Should the price of cement copper hold at this level for another two or three years, the return on investment in this property may be seriously lowered. Other mineral commodities which have undergone severe price drops in recent months include tungsten, antimony, silver, and mercury. Known deposits of tungsten, antimony, and mercury in the United States, with few exceptions, do not have large reserves.

Comparison with Existing Operations

Frequently a mining firm must decide between investment in expansion of an existing mine and investment in a new mine or in exploration of a promising prospect.

Ensign (1969, p. 14-15) has stated,

Copper Range Company is in the fortunate position of owning an ore deposit (White Pine) which is so large that it is susceptible to further development and increased production. This permits us to use the financial facts from White Pine as a "yardstick" against which we can compare potential new mining ventures. As a rule of thumb then, our exploration targets must offer promise of a mining operation which would be at least as profitable, per unit of production, as the White Pine operation. Otherwise our company would probably be better off investing in further expansion of production from the White Pine area.

Copper Range Company (1967, p. 6) reported ore reserves at White Pine sufficient to last for over 40 years at a production rate of 25,000 tons of ore per day.

There is a strong presumption that Kennecott Copper Corporation adhered strongly to this type of policy from the early 1950's into the early 1960's. Reserves at Kennecott's copper properties are immense.
Reserves at the Bingham mine are approximately 1,773,300,000 tons of ore with an average grade of 0.71 percent copper, a large enough tonnage to last over 40 years at the 40,000,000 ton per year rate at which ore was mined in 1970. At the Ray mine, Kennecott's reserves are approximately 736,310,000 tons of ore with an average grade of 0.82 percent copper, and at the Chino mine, 452,307,000 tons having an average grade of 0.78 percent (Kennecott Copper Corp., 1971, p. 11).

During the period 1950 to the present, Kennecott has steadily expanded production at its existing copper properties. Its exploration subsidiary examined several copper properties in the 1950's and early 1960's which were developed by other companies within a few years after being turned down by Kennecott. These mines include Duval Sierrita, Pima, Twin Buttes, Esperanza, and Mineral Park, all in Arizona.

Expansions at existing mines may be highly profitable. For example, at Atlas Consolidated Mining and Development Corporation's Lutopan mine on Cebu, Republic of the Philippines, concentrator capacity was increased from 28,500 tons per day to 35,000 tons per day in 1970 with a capital investment of $1,620,000 (Atlas Consolidated Mining and Development Corp., 1971, p. 6-7).

A new mining venture will almost always be considered more risky than expansion of an existing one. In addition, the capital cost per ton of production capacity will almost always be higher for a new mine than for expansion of an existing one. For these reasons, comparison of the profitability of a proposed new project with the imputed profitability of expansion of existing facilities will frequently, perhaps more often than not, place the new venture in an unfavorable light.
A related policy followed by one major domestic petroleum company interested in metallic and nonmetallic mineral deposits is the use of a 9 percent cutoff DCFROI for expansions of existing facilities and a 12 percent cutoff DCFROI for new ventures.

No one will question the fact that, if a company is in a capital rationing situation and is faced with a choice between a highly profitable investment in an existing mine or a significantly less profitable investment in a new mine, the existing mine should be favored. However, there are three considerations of which mining company management must remain aware. First, there is risk involved in being dependent to too great an extent on one asset. The risk involved in a new venture may be at least balanced by the risk involved in getting more and more dependent on a very small number of operations. The Copper Range Company has one operating mine, the White Pine mine. As pointed out above, the reserves at White Pine are sufficient for over 40 years. An expansion of production at White Pine could provide additional earnings for many years.

However, the White Pine mine has been experiencing labor problems for some time. The company (Copper Range Company, 1970, p. 7) has reported:

... an inability to obtain and keep manpower in sufficiently increasing numbers to meet the requirements not only of expansion but also of mining under adverse physical conditions. For example, although 507 men were recruited for the mining force during the year 1969, the net addition for the year was only 149 men. All these people, whether they stay with us or not, were trained at considerable expense.

The shortage of manpower is particularly great in the skilled trades,
such as mechanics and electricians. The absentee rate is high, parti­cularly over weekends (Ensign, 1970, p. 7-8). As of June 1970, only 7 percent of White Pine's hourly work force of 2,206 employees resided in White Pine, and only 35 percent of the company's 528 salaried em­ployees lived there. The average commuting distance was 80 miles per day round trip, with some men commuting from as far as 100 miles away.

To overcome the high turnover and absentee rates, White Pine is developing an attractive community at White Pine to house over 6,000 people. Hopefully, White Pine mine will overcome its labor problems, but the unfortunate experience of Universal Oil Products Company's Calumet copper operation in the same district must provoke some dis­quiet (Universal Oil Products Company, 1970). Copper Range was also experiencing production problems in mid-1970 as a result of swarms of faults in the mine.

A second important consideration is that it is wrong to screen projects, using the implicit assumption that any amount of money can be invested in an existing operation at the same level of profitability as currently enjoyed.

Third, several small investments in an operating mine, each with a high DCFROI, may not contribute as much to the long-run poten­tial growth in earnings of a firm as a single large investment in a new mine offering a somewhat lower DCFROI.

**Payback Period**

The shortcomings of the payback period as a method of screening or ranking investment proposals have been repeatedly demonstrated in the literature of financial analysis. A very recent example is in a paper by
Hammes (1971, p. 4-5). The fact that the payback period is not a valid project ranking or screening criterion has not impeded its use as such in the mineral industries. However, in many instances, it does seem to be relegated to second or third place in importance in investment decisions on new mines. For example, Ensign (1969, p. 15-16) has said, "Our company uses the Discounted Cash Flow Method of Evaluation. . . . Payout or return of investment through cash flow is another important consideration. Again, we are somewhat flexible on this matter; however, if payout is much over five years, we view the possibilities with a very critical eye."

Some mining projects have a very short payback period. Marcopper Mining Corporation's open pit mine was developed and a 15,000 ton per day concentrator constructed on Marinduque Island, Republic of the Philippines, over a 19-month period beginning in February 1968. "Tune-up operations commenced in September, 1969 and by December, 1969 mill throughput had attained an average of 15,900 tons per day" (Endako Mines Ltd., 1970, p. 23). In addition to the mine and mill, a power plant, dock facilities, housing development, and water handling and tailings disposal facilities were constructed. "The total capital cost for development and construction of mine and mill facilities was $43,000,000(U.S.)" (Endako Mines Ltd, 1970, p. 23).

For the six-months' operation from January 1, 1970 to June 30, 1970, costs per ton of ore milled were U.S. $3.74, including loan interest and taxes but excluding depreciation and depletion charges of U.S. $0.68 per ton.
By the end of 1970, $22,000,000 had been repaid to the consortium of United States banks which had financed the project. In March 1971, an additional $2,500,000 was repaid. Projections made in the fall of 1970 based on the copper price prevailing at that time indicated that "Marcopper would be in a position to fully repay the bank loan by the end of 1971" (Endako Mines Ltd, 1970, p. 24). Dividend payments were expected to commence by the end of 1971.

Copper prices have fallen drastically in 1971. The average price received by Marcopper before smelter deductions was U.S. 64.37¢ per pound in 1970 (Placer Development, Ltd., 1971, p. 10). The current price of copper on the London Metal Exchange is about U.S. 45¢ per pound. Even with reduced prices, the U.S. $42,000,000 loan could be repaid in 1972. Very recently, Placer Development, Ltd., which owns a 40 percent interest in Marcopper, announced that Nippon Mining Company has declared a state of force majeure effective November 1, 1971, which will reduce the amount of copper concentrate which Nippon will accept by as much as 24 percent (Wall Street Journal, 1971, p. 7). All of the 1970 copper concentrate production of Marcopper was sold to Nippon. According to Nippon, the force majeure declaration was brought on by increasingly stricter air pollution regulations, which have forced cutbacks in smelting. This new development should not extend the payback period of Marcopper, particularly if offsetting concentrate sales can be made at favorable prices.

Large projects may have long payback periods. Southern Peru Copper Corporation's Toquepala copper mine in Peru went into production in the first quarter of 1960 after a six-year period of development and
construction involving an expenditure of about $240,000,000 including capitalized interest during construction. The first dividends were paid to the four shareholding companies in the fourth quarter of 1966.

The payback period does seem to be very much alive in equipment replacement decisions and in decisions on modification of metallurgical plants. It is lamentable if higher management has no more faith in the ability of its operating staffs to evaluate such decisions than to provide them with such a non-discriminatory profitability goal as a payback period. In any event, measurement of the true cash benefits and costs of a project is much more complicated than calculating a DCFROI or NPV once the cash flows have been estimated. Cash flows must be estimated for the payback period computation as well as for the DCF measures.

There is a "sophisticated" payback period measure (Bierman and Smidt, 1966, p. 32-33) which does take the time value of money into account, but it is seldom heard of in use. It is only applicable to projects in which the net cash flows are equal in all discounting periods. Neither mines nor trucks yield uniform periodic cash flows, so the method has little practical merit.

Among the reasons for the popularity of the payback period as a project selection criterion are the following. Some investors believe that the shorter the payback period, the higher the rate of return on investment. While in many cases, a short payback period may be indicative of a high rate of return, in general this simply is not true.

A short payback period indicates the possibility of relatively nearby contributions to earnings per share. The truthfulness of this
statement cannot be denied. In view of the relationship between earn­
ings and dividends and share prices, the rapidity with which earnings will be made available can rightly be considered of primary concern to shareholders. A long payback period may well be justified in the minds of shareholders only by strong probabilities of relatively greater earn­nings extending for a long time into the future.

It is useful to calculate the payback period for its informational content from this point of view, but this still does not justify its use as a selection or ranking criterion. The payback period cannot distinguish which of two projects will make the greater contribution to shareholders' wealth over the lives of the projects, which clearly must extend beyond the payback period.

A short payback period is in accord with the liquidity objective of firms, particularly in the short run. Management probably tends to lean more toward this argument for the payback period in times of capital scarcity, such as United States industry has been experiencing in recent years. The planning staffs of one domestic taconite company received instructions in 1970 that replacement of haulage trucks, which had pre­viously been justified on a three-year payback basis, would now have to show a two-year payback.

The problem with this attitude is that the short-run liquidity objective of a firm may run counter to its long-run profitability objective. If a firm is in a situation in which it has to place liquidity so far ahead of profitability in project selection that payback period predominates over profitability, it is possible that its cost of capital is high enough
that most projects would appear marginal on an NPV or DCFROI basis anyway.

Finally, a short payback period is frequently considered to be a form of insurance in an environment showing symptoms of political instability. This can be a very misleading notion. It is the cash flows that follow achievement of payback that determine the profitability of an investment.

It is concluded that use of the payback period as an investment ranking or selection criterion cannot be reconciled with the logic of the DCF methods. However, it should be considered in estimating the possible impact of a project on a company's cost of capital.

**Cost per Unit of Product**

The cost per unit of product, for example, the delivered cost per pound of copper produced, is one of the most important criteria entering into the decision to undertake a new mining project. This was brought out by R. B. Crowl, treasurer of American Metal Climax, in unpublished remarks at a short course on financial analysis sponsored by the Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. in February 1971. He said that if the estimated production cost of metal from a project were in the upper one-third to one-fourth of the range of world production costs, a company might be well advised not to undertake the project even if it looked acceptable on other grounds. The production cost is defined here to include costs of transportation of the product to point of delivery to the buyer.

The vital importance of knowing where the production cost of the project under study falls in the world range of production costs stems
from the unpredictability of mineral commodity prices. A very good example of the significance of production cost is provided by cement copper (copper precipitates). The price of No. 2 copper scrap and heavy wire fluctuates strongly. It is against such secondary materials that cement copper must compete, particularly if one is trying to sell to a buyer other than a custom smelter. Offers of 52¢ per pound of copper contained delivered to a smelter were being received by prospective developers for production from the Copper Mountain and Copper Leach properties near Tyrone, New Mexico, in the first half of 1970. These offers were usually for purchase of all production over an 18-month or 24-month period. The company which eventually acquired the property and brought it into production by heap leaching sold 13 million pounds of cement copper under an advance sales contract for 52¢ per pound.

Currently, the price of No. 2 copper scrap and heavy wire is in the range of 35¢ per pound to 38¢ per pound. In January 1970, the author estimated the cost of production from the Tyrone properties mentioned above at 37.7¢ per pound of copper contained in cement copper form. This cost included depreciation and depletion, which would have run 3¢ to 5¢ per pound, depending on the terms of the property acquisition agreement and the size of plant installed. This estimate was not made for the company now operating the mine. That company has encountered some metallurgical problems. Unless the price of copper rises significantly, the future of this leaching operation does not seem too bright.

Generally, new mines are evaluated using a quite conservative metal price. For example, it is not unusual to find copper properties
being evaluated today at prices in the neighborhood of 42¢ per pound.
Feasibility studies on which financing was obtained by Freeport Sulphur
Company for its Ertsberg copper project in Indonesia were based on a
"principal producers price" of 40¢ per pound and on an average cost of
about 9¢ per pound for smelting, refining, freight, and miscellaneous
charges (Douglas, 1970, p. 2). The principal producers price is the price
received by principal producers in the European market. Freeport Indo­
nesia, Inc., a subsidiary of Freeport Sulphur, authorized the detailed
feasibility study on the Ertsberg project in January 1969. The final re­
port was completed in December 1969. For the year 1969, the average
European copper price was about U.S. 66¢ per pound.

Prain (1970, p. 11) has estimated the Free World average cost
of competitive copper at 32¢ per pound in 1969. Royalties and export
taxes payable to the Zambian government by producers in Zambia
amounted to 3.5¢ per pound of this average. In April 1970, the royalties
and export taxes were rescinded. Ignoring these costs, the world aver­
age cost would be 28.5¢ per pound for 1969.

The world average cost today is undoubtedly higher than 28.5¢
per pound due to the problems at Chilean mines (Metals Week, Aug. 30,
1971, p. 20-22) and inflation in the United States. The world average
cost today is undoubtedly over 30¢ per pound and may be closer to 32¢
to 33¢ per pound. The range of production costs is from less than 25¢
per pound to over 40¢ per pound.

If the cost of production from a new copper mine is projected to
be in the upper one-third or one-fourth of world production costs and the
mine is evaluated at a 42¢ per pound copper price, it is not likely that
the project will promise a high DCFROI. From this point of view, there will probably be no conflict between the results of DCF analysis and the policy of rejecting copper mines with a production cost in the upper one-third to one-fourth of world production costs. This statement is probably even more true for lead and zinc mines. It may be less true for bauxite mines. The cost of mining bauxite, the chief ore of aluminum, may represent as little as five percent of the cost of producing aluminum. The cost of mining copper, lead, and zinc ores may represent 20 percent of the cost of producing these metals.
COST OF CAPITAL AND DISCOUNT RATES

Appropriate Concepts

A firm's cost of capital may or may not be used as the discount rate in computation of NPV's of proposed projects, or as the minimum acceptable DCFROI. For the firm whose objective is to maximize profits, the cost of capital, the discount rate, and the minimum acceptable DCFROI should all be the same number.

It is difficult to define the cost of capital and even more difficult to measure it. At least conceptually there are marginal and average costs and short-run and long-run costs.

It seems reasonable the the proper cost of capital for use in capital budgeting is the firm's long-run marginal cost of capital. The marginal cost to be used is not to be confused with the marginal cost of one component, such as debt. Treasurers of corporations are quick to point out that if a corporation borrows for projects which have a relatively low return on investment because the after-tax cost of debt is low, the corporation will in time discover it has used up its borrowing power. It may then face a situation in which it has to pass up an attractive project or obtain new equity financing at a high cost. These treasurers are absolutely correct when by marginal cost they refer to the short-run marginal cost of debt.

It must be emphasized that the marginal cost to be used is a long-run marginal cost. It is a weighted average of the long-run marginal costs of all the components of capital which the firm employs.
When a new mining project requires new financing, the cost of the new capital must be incorporated in the overall cost of capital to be used in calculating NPV or to be used as a minimum acceptable DCFROI. The effects on cost of capital of undertaking a large new mining project cannot be ignored in evaluation of the project.

The cost of debt and the cost of capital raised by preferred stock present no serious conceptual problems of computation. Computation is rather mechanical. The cost of debt from a particular source and of preferred stock financing can always be computed by the expression

\[
\sum_{t=0}^{n} \frac{C_t}{(1 + k)^t} = 0
\]

with \( C_t \) the net amount of cash received from or paid to the source of financing in period \( t \), and \( k \) the per period explicit cost of capital. The expression is solved for \( k \). As an example, if a firm borrows $100,000 and has to make five year-end repayments of $25,046 each, the expression is

\[
$100,000 - \sum_{t=1}^{5} \frac{25,046}{(1 + k)^t} = 0.
\]

Solving this expression for \( k \), shows that \( k \) is about 8 percent. This expression can be used as well to compute the explicit cost of capital raised by sale of common stock or of an asset. The expression is of no use in assigning a cost to equity capital in the form of retained earnings because the cost of retained earnings is properly an implicit opportunity cost.
Cost of Internally Generated Funds

The following discussion applies to the funds resulting from retention of earnings and deductability of depreciation, depletion, and amortization in computation of taxable income. Funds from these sources are collectively referred to as internally generated funds.

There are two definitions of the cost of internally generated funds financing which are worth considering. The first definition is that the cost is an opportunity cost and is equal to the DCFROI of the best company project or stockholder investment opportunity which would be foregone if the project under consideration were accepted. The second definition is that the cost is the minimum DCFROI which must be earned on a new project to leave the value of equity unchanged. These two definitions actually are only two ways of saying the same thing. Presumably, if a company invests funds in a project which is just as good as but no better than the best alternative inside or outside investment opportunity, the value of equity will remain unchanged.

A major problem in measurement of the cost of using internally generated funds is the problem of determining what the stockholders' opportunity cost is. The problem arises not so much from a lack of knowledge of what alternative investment opportunities are available to the stockholders, but from the fact that there are many stockholders whose investment opportunities are different and whose tax positions are different. Sometimes the suggestion is heard that there is a tendency for a company's shareholders to be entities with the same attitude toward risk, growth, and other factors affecting investment policy. Even were
this suggestion true, its significance would be overshadowed in many situations by the different tax positions of shareholders.

R. P. Koenig (1964, p. 123), then president of Cerro Corporation, wrote:

Since large stockholders who may have a direct or at least implicit voice in corporate management usually have no desire to increase their cash income not only due to double taxation, but also to the extraordinary "dis-investment" effect of surtaxes on personal income, cash dividends are more often than not kept at a respectable minimum; the result of this, particularly in the older companies engaged in industries which are on the upper reaches of the usual growth curve and consequently have little internal demand for new capital, is to accumulate large amounts of cash.

Tax-free institutions which might also be shareholders of Cerro might not be expected to have the same attitude toward dividends as the large shareholders Koenig refers to.

Another example of conflict over reinvestment policy is provided by the opposition of Golconda Mining Corporation to Hecla Mining Company's investment in the Lakeshore copper project. This was discussed earlier in the dissertation. The opportunity cost of the earnings to be spent on the Lakeshore project was apparently higher to Golconda than to Newmont Mining Corporation, which is also a shareholder of Hecla. A large portion of Golconda's income was Hecla dividends. The same is not true of Newmont's income. Newmont holds an undeveloped, apparently marginal copper deposit about ten miles west of the Lakeshore deposit. Conceivably there might be some beneficial effect on Newmont's deposit in the existence of a reduction plant at the Lakeshore property.

In light of these considerations, it is apparent that there is no single cost of internally generated funds, but a schedule of many costs,
the opportunity costs of each shareholder. Management could think of the cost of internally generated funds or equity as a weighted average of the costs of each shareholder, with the weights being the percentage of the outstanding shares held by each respective shareholder, but this is impractical. Insofar as the minimum acceptable DCFROI is influenced by these considerations, corporate management will simply be forced to seek a compromise or follow majority rule.

It has been suggested (Weston and Brigham, 1966, p. 308) that the cost of retained earnings is less than a stockholder's required rate of return because of taxes on dividends and brokerage fees involved in re-investing net income from dividends. An expression suggested (Weston and Brigham, 1966, p. 308) for estimating the cost of retained earnings is

\[ k_r = k(1 - T)(1 - B) \]

with \( k_r \) the cost of retained earnings, \( k \) the stockholders' required rate of return, \( T \) the stockholders' marginal tax rate, and \( B \) the brokerage fee expressed as a decimal. This expression would also be used to calculate the cost of "depreciation, depletion, and amortization-generated" funds.

To a certain degree this is a useful concept. However, it should be viewed with a somewhat critical eye. If \( k = 0.12, T = 0.50, \) and \( B = 0.10 \), the above expression would imply that \( k_r = 0.054 \) or 5.4 percent. If a corporation were to have a capital structure composed of 50 percent debt at an interest rate of 8 percent and 50 percent equity, this would imply that the company should accept projects with a DCFROI higher than 4.7 percent. This is obviously untrue. Any company which
followed such a policy would soon find itself in financial trouble. This DCFROI would hardly keep pace with inflation. The outlook for earnings and growth of earnings from investments with a 5 percent DCFROI would not be such as to keep the market value of equity unchanged. There is a point below which the outlook for earnings and growth in earnings becomes predominant over considerations reflected in expressions such as the above one for $k_f$.

**Risk and the Discount Rate**

The cost of equity capital is usually assumed to include a risk component which reflects shareholders' uncertainty about the outlook for earnings and dividends. If this is true then the practice of adding several percentage points to the cost of capital to arrive at a proper discount rate seems unwarranted. In a sense it is "double-counting" risk.

It is difficult to decide how many percentage points should be added to the cost of capital to allow satisfactorily for the risk in a project. In the end, such a number must be very arbitrary. Use of risk-adjusted discount rates may be dangerous in that by seeming to offer insurance against risk, it leads to neglect of the critical thinking needed in risk analysis. This is discussed in more detail in the next chapter.

**Exploration and Development Costs and the Discount Rate**

A frequently asked question is whether the discount rate or minimum acceptable DCFROI from mining projects should be higher than for other industries because of the rapidly increasing cost of discovery and development of new mines. This question is not only of significance
for the smaller companies whose ore bodies may be small and thus wasting assets in a very dramatic sense, but is also of great significance for larger companies whose reserves may be very large but who must continue to find large new deposits if they are to maintain their share of growing mineral commodity markets.

Malozemoff (1970) has said:

To engage in exploration requires money, lots of money these days. Besides the large sums necessary for exploration, the subsequent requirements for funds to develop a new deposit and to put it into production are by former standards very high, partly because of the higher cost of utilizing more advanced technology, partly because deposits are either deeper, or more inaccessible or lower grade, or more refractory to extraction of metals from them. Sums of 200, 300 or even 400 million dollars are today not unusual for a single enterprise. . . .

To support continuous extensive exploration and development of new mines requires investment of equity funds, and therefore high earnings. I dare say that unless we strive for an after-tax return on investment approaching 15 to 20 per cent, it would be difficult to keep the company growing.

He pointed out that the average return on Newmont's investment in its presently producing ventures was 36 percent in 1969.

MacWilliam (1966, p. 39) has written:

Grass-roots prospecting today is so expensive and the risks so high that time and time again mining houses will enter consortia to carry out prospecting in some new area. The percentage participations and, indeed, the partners, will vary from project to project, but it is common today to find four, five or six mining houses joining together to prospect or develop an area where 15 to 20 years ago it would have been left to individuals or perhaps to a single mining house to carry out the work.

Why has this change come about? I would think that partly it stems from the risks and cost of prospecting . . . but even more because the sort of mine that is being sought requires normally very large amounts of finance.

High risk and unpredictable time lags for success are not peculiar to mineral exploration. Rose (1969, p. 5) has presented a very
interesting comparison between exploration and basic research in the electronics industry. He concludes that "although the probability of failure for a single investment outlay on exploration is greater than in most other lines of activity, it is not obvious that the risks are dissimilar from those faced by companies operating in industries where technological innovation is proceeding at a fast pace."

It seems reasonable that a higher DCFROI will be required to ensure future significant growth of earnings for mining companies than for companies in some other industries. However, in practice, the investment policies of mining corporations do not seem to follow strictly the notion that a very high DCFROI must be required from a new project. It has been pointed out in Chapter 1 that one large corporation in 1970 was willing to accept a 10 percent DCFROI if a project offered stable earnings for a long period. Other large corporations have indicated 12 percent would be acceptable for new mining projects. A number of companies use 15 percent as a cutoff DCFROI. An executive of one uranium producer set a cutoff DCFROI of 30 percent on new mining projects and stated explicitly that this was to allow for the high cost of exploration; the successful projects must repay the cost of unsuccessful exploration.

It is apparent that while all mining companies agree that exploration is risky and while all are faced with rapidly rising development costs, there is no agreement on the level at which the discount rate or minimum acceptable DCFROI should be set to guarantee that no project will be undertaken which cannot generate its proper share of rapidly rising capital requirements.
Exploration projects should simply not be undertaken if there is no chance of finding a deposit which will earn a satisfactory return on investment, including the capital investment which must be made in exploration. Once a deposit has been found, no company will refuse to mine it because exploration funds already spent, if included in the DCFROI calculation, reduce the DCFROI from 15 percent to 13 percent. Such costs are sunk costs.

It is concluded that in evaluating a deposit already discovered, a high discount rate should not be used on the basis that exploration and development costs are rising. The proper time to take these rising costs into account is when exploration policy is developed and exploration programs are planned.

Interest in Computation of Cash Flows

In spite of very clear discussions of this matter in the literature of capital budgeting (Quirin, 1967, p. 64-65), major errors involving interest continue to be made in cash flow analyses of mining projects by some mining companies and by some engineering concerns. Interest charges are not a proper deduction from gross income in estimating cash flows for use in DCF analysis. The interest factor is taken care of by discounting. Interest is not being ignored in DCF analysis when it is not deducted in estimating cash flows.

It should also be noted that since the debt component of the cost of capital is usually taken as an after-tax cost of debt, it is also incorrect to reduce income taxes to allow for the deductability of interest when computing cash flows for DCF analysis.
DCF measures of profitability are not the only profitability criteria to be used in financial analysis. In other measures, interest is a proper deduction. For example, interest must be deducted in computing the net contribution of a project to earnings per share. Commercial and investment bankers will desire a project to yield a yearly net cash flow which is some multiple of debt amortization cost.
ANALYSIS OF RISK FACTORS IN MINING PROJECTS

In the first section of this chapter, a number of examples of risk in mining projects are discussed. It is proposed that elements of risk can usually be traced back to two sources, geology and people. A third source, engineering materials, contributes far less risk to a project than the first two. Any analysis of risk should begin by tracing elements of risk back to their source.

In the second section, several techniques of risk analysis are described. Basically, there are two choices. One is the study of the effects on profitability criteria of risk-adjusted cash flows, earnings, or other measures of economic benefits or costs, and the second is the study of the effects of risk-adjusted discount rates on profitability criteria. It is proposed that since adjustment of benefits or costs tends to make the effects of risk more explicit in the analysis, it is almost always preferable to adjust them rather than to adjust the discount rate.

Finally, the applicability of risk analysis techniques to specific problems in mining industry capital budgeting is discussed. An attempt is made to show that not all methods of analysis are equally efficacious in all situations. Some methods currently in vogue are being misapplied, and even where correctly applied they sometimes do not provide really useful results. Other methods when properly applied are quite generally useful.
Elements of Risk in Mineral Industry Projects

A few of the factors which introduce risk into a project are ore reserve estimates, commodity prices, operating costs, and metallurgy.

Ore Reserve Estimates

Any preconceived notion that a porphyry copper deposit is a homogeneous ore body with all the ore about equally amenable to concentration is quickly dispelled by visits to a few of the mines and concentrators in the southwestern United States. Varying ratios of oxide to sulfide copper, gangue minerals which affect concentrate grade, grindability, moisture content, and wood from old underground workings are among the factors that make the job of the grade control engineer a challenging one. It is a tribute to these engineers that so many problems are so well overcome.

An awareness that this internal variability exists should make the ore reserve estimator approach his job with a good degree of humility. It is apparent that, particularly in the case of a deposit with no production history, there is risk involved in the ore reserve estimate.

Distribution and grade of ore are the result of geologic processes. To make accurate ore reserve estimates, the engineers or geologists must have an adequate understanding of the geology of the deposit under study. Moreover, an estimation method applicable to that type of deposit must be used. The risks of inaccuracy in prediction of grade and distribution of ore can thus be traced directly to geology and the people who make the estimates. Enough samples must be taken to draw a sound geologic picture. A reliable reserve estimation method must be applied to the sampling results.
Commodity Prices

Commodity prices are determined by buyers and sellers, by men whose behavior in the market generally reflects the operations of laws of supply and demand. The uncertainty in the future of commodity prices finds its seat in the minds of the men who buy and sell. It is not only events, but the way buyers and sellers see events, the expectations of buyers and sellers, which determine the course of commodity prices. To forecast the future of commodity prices during some time interval, it is necessary to predict reasonably well the way buyers and sellers are likely to react to probable future events.

The type of problem which must be faced in predicting commodity prices is clearly illustrated in an excellent analysis of the behavior of monopolists by Machlup (1952, p. 552-557). He analyzes the behavior of sellers who, although really in a monopoly position, may or may not see themselves as in such a position. Monopolies do not exist in most mineral commodity markets, but Machlup's approach to analysis is applicable in any market structure.

Machlup's confident monopolist is a man who, realizing the security of his position, is unconcerned about safeguarding it. Machlup states: "There is nothing that compels us to assume that the confident monopolist's long-range monopoly policies will be dominated by the desire to maximize long-run money profits. . . . a perfect monopolist sure of his position and confident of his profits can well afford to pursue other objectives."

In contrast to the confident monopolist is the pessimistic monopolist whom Machlup describes as "a monopolist whose position we
regard as safe—because we find the probability of newcomers invading his bailiwick to be very small—but who himself is convinced that newcomers' competition will arise any moment and will spoil his business. . . . his conduct is apt to be rather unfortunate from the point of view of society."

Machlup also describes a third type of monopolist, the monopolist who sees his position as safe so long as his prices are not too high, his profits are not too large, the quality of his products is kept high enough, and improvements in his technology and organization come rapidly enough.

While an objective observer may be able to determine another man's situation accurately, that man's course of action will depend on how he sees his situation, not how the objective observer sees it. The monopolist's behavior will never be predictable with certainty, and will often be highly unpredictable.

Operating Costs

Haulage costs in an open pit mine include operating labor and materials and labor and materials for repairs and maintenance. Labor costs can be somewhat difficult to predict. Fuel consumption is not too much of a problem to predict. Tire costs are a large part of the haulage cost per ton of ore or waste but should be reasonably predictable. At a porphyry copper operation in the Southwest, tire costs recently rose rapidly to an unacceptable level. A program of inquiry into each haulage truck tire failure was initiated with drivers and supervisors being exhorted to improve. The rate of tire failures dropped back toward 50
percent of the level to which they had risen. The driving practices of the men behind the wheels were contributing strongly to higher than predicted tire costs.

As another example of the uncertainty in operating cost estimates, the cost of stoping and stope preparation in the panel caving operation at Urad, Colorado, may be considered. Kendrick (1970) discusses a problem which American Metal Climax Inc. encountered there. The ore body did not cave as predicted due to unforeseen rock stress patterns. The company had a geologic problem which it had not previously encountered. Kendrick reports that the cave-assist program added $0.16 per ton of ore mined to the mining cost.

Metallurgy

Cuthbertson (1961) discusses metallurgical problems which have been encountered at the Climax molybdenum mine in Colorado. One of the problems he mentions is an excellent example of risk associated with metallurgy and how this risk may be traced back to geology, specifically to gangue minerals and their reactions on breaking in mining. He refers to the problem as the "clay problem." The "clay problem" was not encountered until mining progressed from the Phillipson level to the Storke level. As soon as a substantial tonnage of ore was mined from the Storke level, a serious drop in recovery associated with intense slime flocculation was noted. A full-scale investigation traced the flocculation of the clays back to the presence of acid salts in the ore. The salts had been essentially absent on upper levels. This was a geologic condition which had not previously been encountered and was not predicted by exploration or metallurgical test programs.
It is very laudable to make available to the industry, as American Metal Climax Inc. has done, information on problems like this and how they have been solved. The availability of such information should help others to reduce the risks involved in their own projects.

Before leaving this first section, it should be pointed out why it is so important to be able to trace risk back into its real sources. The reason is that the nature of the source of an element of risk has everything to do with the selection of the method used to analyze its possible impact on the project. While the shearing strength of an engineering material may be quite accurately inferred through application of statistical theory to test data from samples of the material, the non-deterministic behavior of men may render such methods practically useless in the prediction of metal price movements over the next five years.

Techniques of Risk Analysis

There are basically two techniques for risk analysis. Risk can be taken into account by adjusting cash flows, earnings, or other measures of economic benefits or costs, or by adjusting the discount rate or capitalization rate. What generally happens is that both are adjusted. However, the two are treated separately in this discussion to clarify better their individual merits.

For the purposes of this dissertation, the following discussion concentrates on DCF analysis, with the understanding that the same or analogous risk analysis methods apply to other methods of investment analysis.
The NPV equation is written:

\[
NPV = \sum_{t=0}^{n} \frac{B_t}{(1 + r)^t} - \sum_{t=0}^{n} \frac{C_t}{(1 + r)^t}.
\]

\(B_t\) and \(C_t\) are the cash benefits in period \(t\) and cash costs in period \(t\), respectively; \(r\) is the cost of capital used to discount the cash flows; \(t\) is any time period of fixed length; and \(n\) is a number indicating the last time period to be considered in the project analysis.

To calculate the DCFROI as a measure of profitability, the following equation is used:

\[
\sum_{t=0}^{n} \frac{B_t}{(1 + r)^t} - \sum_{t=0}^{n} \frac{C_t}{(1 + r)^t} = 0
\]

where \(r\) is the DCFROI. The equation is solved for \(r\). The net cash flow in period \(t\) is \(B_t - C_t\).

Four examples of the class of risk analysis methods based on adjusting cash flows will be considered: sensitivity analysis, probability theory, theory of statistical inference, and certainty equivalent analysis. The use of risk-adjusted discount rates, including Hoskold's approach, will then be discussed.

Methods Based on Adjusting Benefits or Costs

**Sensitivity Analysis.** The term sensitivity analysis as used in this dissertation means setting up algebraic expressions, such as the DCFROI or NPV equation, and deriving information on the sensitivity of the DCFROI or NPV to variations in such factors as average grade of mill feed, mill recovery, repair costs, or other operating and economic variables. This is a very general use of the term.
This form of risk analysis is very straightforward in application. A mining project can be studied in considerable depth in terms that are completely familiar to the engineers and geologists designing and evaluating the project.

Answers to the following types of questions are readily found.

1. What would be the effect on the DCFROI of the project if the price of the mine's product is 10 percent lower than management has estimated in the first two years of production, the same as estimated during the next two years, and 5 percent higher during the remaining years of life?

2. What would be the effect on annual cash flows if an unexpectedly high ingress of water in the mine raises mining costs 10 percent in the first two or three years of production?

3. How much in error does the haulage cost estimate for size one truck have to be before the use of size two trucks would appear to be an attractive alternative?

Sensitivity analysis answers questions such as the above. Mine management is much more likely to ask such questions than to ask what the expected value of the DCFROI may be if the probability distribution of labor costs is given by this or that function in 1972 and following years.

While sensitivity analysis, as the term is used here, may lack mathematical sophistication, it is extremely useful, and that is what is important. A detailed cash flow model can be written relatively quickly and programmed for a digital computer. Many sensible questions can then be answered quite rapidly.
Probability Theory. While in practice it is difficult to separate probability theory and the theory of statistical inference, it may be useful to recall the difference between them. If an analyst understands a certain probabilistic mechanism, probability theory permits him to use his knowledge of the mechanism to make predictions about the results of its operation. On the other hand, if an analyst has only imperfect knowledge of the mechanism which is producing certain observed data, the theory of statistical inference helps him to select rules for guessing which of a group of possible mechanisms is the one actually at work. It also permits him to estimate the accuracy achievable by his guessing procedure. Assuming that an analyst feels reasonably confident that the statistical method he has selected has put him onto the mechanism at work, he can use probability theory to predict future values of the variable of interest.

To restate the explanation of probability theory, if an analyst can assign a probability distribution to an exhaustive list of mutually exclusive outcomes of an event, probability theory permits him to calculate the expected or mean outcome of the event as well as certain statistics which may be interpreted as measures of the risk associated with the expected outcome.

The assignment of such a distribution is in practice seldom simple. It is conceptually quite simple in situations in which the possible outcomes of a particular event are independent of outcomes of other events. It can be conceptually quite complex in situations where such independence does not obtain and it is necessary to use the theory of conditional probability.
Probabilistic models may be discrete or continuous. An example of a discrete model would be the following:

<table>
<thead>
<tr>
<th>Possible Net Present Values</th>
<th>Probability p(X_i) of Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,000</td>
<td>0.2</td>
</tr>
<tr>
<td>$2,000</td>
<td>0.3</td>
</tr>
<tr>
<td>$3,000</td>
<td>0.3</td>
</tr>
<tr>
<td>$4,000</td>
<td>0.2</td>
</tr>
</tbody>
</table>

The above must be an exhaustive list of mutually exclusive outcomes. The X_i, instead of being NPV's, could be mining costs, diesel fuel consumption, mill recoveries, or any of a host of other variables.

Using such a distribution it is possible to calculate the expected NPV and certain parameters considered to be measures of the risk associated with the project. In the example which follows the coefficient of variation is calculated as an example of such a measure of risk. The procedure is shown below.

\[
\begin{array}{cccccc}
X_i & P(X_i) & X_i P(X_i) & X_i - u & (X_i - u)^2 & (X_i - u)^2 P(X_i) \\
1000 & 0.2 & 200 & -1500 & 2,500,000 & 450,000 \\
2000 & 0.3 & 600 & -500 & 250,000 & 75,000 \\
3000 & 0.3 & 900 & 500 & 250,000 & 75,000 \\
4000 & 0.2 & 800 & 1500 & 2,250,000 & 450,000 \\
\end{array}
\]

mean = u = 2500

variance = \(\sigma^2 = 1,050,000\)

The expected or mean NPV is $2500. To find the coefficient of variation, the standard deviation \(\sigma\) is first calculated.

\[\sigma = \sqrt{\sigma^2} = 1025.\]
Then the coefficient of variation $C(X)$ is found.

$$C(X) = \frac{\sigma}{\mu} = 0.41.$$ 

Before beginning the calculation, it was remarked that there is no value in calculating the coefficient of variation of the outcome of the project because we already know exactly what the probability of each outcome is. Thus, if one is asked what the probability is that the outcome will be within $600$ of the expected NPV, one can answer immediately $60\%$. The mean NPV is $2500$. The possible NPV's of $2000$ and of $3000$ are the only ones within $600$ of the mean. Summing the probabilities of these two outcomes gives a probability of $0.6$ or $60\%$. As long as the probability distribution of outcomes is known, questions of this type can always be answered. Although a great number of examples of calculation of the coefficient of variation for a known probability distribution are presented in the literature of financial analysis, there is little reason for it, unless it is for the purpose of condensing data for comparison of projects.

However, if the probability distribution of outcomes is not known, but one has instead only a series of observed outcomes to work with, the variance or coefficient of variation of the observations can be calculated as one method of developing some information on the distribution.

This example illustrates the basic approach of probability methods. Of course, sophistication of the analysis can be increased. The value of such sophistication can only be determined in light of the nature of the particular problem at hand.
A continuous probability distribution function can sometimes be postulated from observed data by statistical methods. Simulation programs which make use of such postulated continuous distributions to do what has been illustrated in the example have been written for digital computers. Hertz (1964) has written an interesting paper on this subject.

A very basic assumption made at the beginning of this discussion of probability theory should be reexamined. This assumption is that the probabilistic mechanism at work is known. In other words, it has been assumed that the postulated probability distribution is correct. The validity of everything else done depends on the validity of the initial model. While a probability distribution of some physical property of drill steel, fuel consumption of a haulage truck, or other such variable may be quite reliably inferred from mine records or manufacturer's specifications, it is quite another matter to develop such a distribution function for the grade of nickel in a laterite deposit.

**Statistical Inference.** As mentioned previously, the theory of statistical inference helps an analyst to select procedures for analyzing data which will permit him to make intelligent guesses as to the nature of the mechanism which produced the data. The theory also helps him to estimate the degree of accuracy achievable by various guessing procedures.

One example of the application of statistical theory to analysis of risk in a mining project is the fitting of a curve, for example, by the least squares technique, to the last two years' blast hole drilling costs to help predict costs over the next year. Another is trend surface analysis of drill hole assay data to predict grade distribution in an ore body.
As a general rule, when trying to develop a model which will permit prediction of the value of a physical property of some engineering material, there is hope for reasonably good results. Some very excellent results have been achieved in the area of quality control. However, the more that the risk in a mining or milling cost estimate has its source in geology, the more caution is required. Finally, the more that future events, for example, commodity price changes and political actions, depend on the expectations, appraisals, and moods of a relatively few men, the less confidence is justified in the ability of statistics to predict the outcome.

Statistics cannot reveal what level of demand for copper might exist or what decisions on use of copper might be taken with an assured price over the next 10 years of 45¢ to 50¢ per pound as opposed to 55¢ to 60¢ per pound. Statistics cannot foretell what the policies of the executives of Chile, Zambia, the Congo, or Peru will be over the next five years or, more realistically from the point of view of new mine financing, over the next 10 to 20 years.

Certainty Equivalent Analysis. In this method of analysis the cash flows are adjusted downward to reflect risk or uncertainty by multiplying them by "certainty equivalent coefficients" \( a_t \). The NPV equation becomes

\[
NPV = \sum_{t=0}^{n} \frac{a_t C_F_t}{(1 + i)^t} \quad 0 \leq a_t \leq 1
\]

where \( i \) is a risk-free discount rate, for example, the interest rate on treasury bills and \( C_F_t \) is the cash flow in time period \( t \).
The certainty equivalent coefficients are made to decline as risk increases and time increases. If \( a_t = 1 \), receipt of the cash flow is certain; if \( a_t = 0 \), the cash flow will not be received.

If a company is considering a $10,000,000 investment expected to yield cash flows of $5,000,000 in each of three succeeding years, the company might assign certainty equivalent coefficients of 0.9 to year 1, 0.8 to year 2, and 0.6 to year 3. Certainty equivalent cash flows \( a_t \times CF_t \) are calculated as follows:

<table>
<thead>
<tr>
<th>Period</th>
<th>Cash flow ( \times a_t = a_t \times CF_t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(-10,000,000 \times 1.0 = -10,000,000)</td>
</tr>
<tr>
<td>1</td>
<td>(+5,000,000 \times 0.9 = +4,500,000)</td>
</tr>
<tr>
<td>2</td>
<td>(+5,000,000 \times 0.8 = +4,000,000)</td>
</tr>
<tr>
<td>3</td>
<td>(+5,000,000 \times 0.6 = +3,000,000)</td>
</tr>
</tbody>
</table>

Assuming a risk-free interest rate of 4 percent, the cash flows are discounted as follows:

\[
\text{Net Present Value} = \sum a_t \times CF_t \times \text{discount factor} = \text{present value}
\]

\[
\begin{align*}
-10,000,000 \times 1.000 & = -10,000,000 \\
+4,500,000 \times 0.962 & = +4,329,000 \\
+4,000,000 \times 0.925 & = +3,700,000 \\
+3,000,000 \times 0.889 & = +2,667,000 \\
\end{align*}
\]

Net Present Value \( +696 \)

This method seems very unsatisfactory from the point of view of the highly subjective nature of the estimates of the certainty equivalent coefficients. How does one estimate them? This is no trifling matter. Moreover, if it is possible to estimate them, why is it not equally possible to estimate the "cash consequences" of the factors giving rise to
them and use such "cash consequences" in the cash flow estimates. The information carried by the certainty equivalent coefficients is of such questionable value that this method is not considered further in this dissertation.

Risk-adjusted Discount Rates

Under these methods the degree of uncertainty involved in a project is taken into account by increasing the discount rate to some number higher than the firm's cost of capital. This is unquestionably the most common method of handling risk and uncertainty in use in the mining industry.

For the firm which desires to maximize profits, the appropriate discount rate is a weighted average of the marginal costs of capital from the firm's various sources of capital. The firm must estimate the weighted average of its expected long-run marginal costs of debt and equity capital. The cost of equity capital, that is, the opportunity cost of capital of the common stockholders, is the most difficult to measure, as discussed in Chapter 2. It can be thought of as a sum

\[ k = i + j, \]

where \( k \) is the cost of equity capital, \( i \) is safe, long-term interest rate, and \( j \) is a risk premium that stockholders consciously or unconsciously apply to common stock. One expression which has been suggested for \( j \) is

\[ j = s \text{Var}(g), \]

where \( s \) is a risk aversion coefficient (actually a schedule), and \( \text{Var}(g) \) is the expected variance in the growth rate of dividends (Lerner and Carleton, 1966, p. 114).
The important thing to recognize is that if a firm has made a good estimate of its marginal cost of equity capital, this estimate already includes some allowance for risk. The practice of arbitrarily adding a high risk factor to a well-calculated cost of capital can defeat the principal objective of the firm, the maximization of the stockholders' wealth, by causing the firm to reject good projects.

Mining engineers and geologists are generally familiar with some other variations of risk-adjusted discount rate methods of allowing for risk. Among these are the Hoskold method and the Morkill method, with the Hoskold method probably the most popular. The Hoskold formula, which dates from 1877, as applied to uniform annual income, is

\[ HPV = \frac{CF}{(1 + r)^n - 1} + r' \]

with HPV the Hoskold present value, CF the annual cash flow to be generated by the mine, r a capital redemption rate of interest, and r' a speculative rate of interest. The purchase price and/or capital investment required for the mine is deducted from the HPV to arrive at a Hoskold net present value. Parks (1957) provides many examples of the application of the Hoskold formula.

There has been a great deal of well-justified criticism leveled at the Hoskold method in recent years, for example, in regard to the speculative rate of return and the irrelevance of the sinking fund assumption (Hammes, 1971, p. 10; Douglas, 1967, p. 1-2; Marston, Winfrey, and Hempstead, 1953, p. 329-332). Hammes (1971, p. 10) states: "The speculative return is calculated on the initial investment and is not
reduced as the investment is recovered. For this reason, the method generally undervalues the project. Further, the concept of a sinking fund is incompatible with the concepts of modern asset management."

Good discussions of the Morkill formula, as well as the O'Donahue formula and the Grimes-Craigue formula, may be found in Parks (1957, p. 345-356). These methods have all been proposed for mine valuation and have met with more or less enthusiasm.

Perhaps there are two reasons why high discount rates are frequently used. The first is the anticipation of a calamity, even though often the probability of a calamitous event may be quite low. The problem with use of a high discount rate for this reason is that it simply offers no protection to the investor. If halfway through the development of a project, or two years after it is underway, the company's assets are expropriated or a severe downturn develops in the market for the company's product, the fact that a very high discount rate was used in valuation will be small consolation to the investor.

The other reason for using a very high discount rate is the anticipation that some adverse condition will be encountered which will gradually exert more and more downward pressure on cash flows. As mine workings reach greater depths weight problems will send maintenance costs soaring or increasing rock temperatures will drastically reduce the efficiency of labor. A valid question in such situations is what cash outflows have been allowed for preventive measures or corrective measures in case such circumstances actually arise. If no allowance has been made for such costs, yet it is considered that such circumstances are probable, one may ask why allowances have not been made. If they have
been and a high discount rate has still been used, the design and planning engineers may not have real confidence in their proposed preventive or corrective measures.

The probability of passing up a good project is very real when the average grade of reserves is shaved for conservatism, an unduly large "safety margin" is added to operating costs, and then a 20 percent discount rate is used.

**Applicability of Risk Analysis Techniques**

**Ore Reserve Estimates**

In the first section of this chapter, it is argued that the risks of inaccuracy in prediction of grade and distribution of ore can be directly traced to geology and to the people estimating the reserves. Enough samples must be taken to draw a sound geologic picture. The engineer or geologist must use an ore reserve estimation method which is valid for the type of deposit under consideration.

If the project geologist or engineer can estimate the possible degree of error in his reserve estimate, sensitivity analysis can be used to study the effect this degree of error could have on the outcome of the project. There is no use in having recourse to probability methods to measure the effects of uncertainty in an ore reserve estimate unless the geologist can provide a probability distribution of the grade of the ore in which he has reasonable confidence. Such a distribution might be:
<table>
<thead>
<tr>
<th>Average Grade</th>
<th>p (average grade)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.65% Cu</td>
<td>0.2</td>
</tr>
<tr>
<td>.68</td>
<td>.4</td>
</tr>
<tr>
<td>.70</td>
<td>.3</td>
</tr>
<tr>
<td>.77</td>
<td>.1</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
</tr>
</tbody>
</table>

Particularly in the case of new deposits, the chances of a geologist or engineer being able to do this accurately are close to nil. It would seem that little is to be gained by such a procedure, particularly in view of the highly subjective nature of any such distribution.

Statistical methods are reported to be capable of yielding reliable results in at least one type of deposit, the gold deposits of South Africa (Pirow and Krige, 1967, p. 177-185). Enough data have been available from mining of those deposits to permit the development of statistical procedures for grade prediction. On the other hand, in those cases known to the author where trend surface techniques have been experimented with at porphyry copper mines, the results have not been satisfactory.

The best chance of being able to use statistical methods, or any other methods for that matter, to arrive at an estimate of the uncertainty in an ore reserve computation, and thus the contribution of this risk element to the uncertainty in the cash flows from mining, exists at operating mines where reasonable production histories of the deposits are available. This might be the situation when an expansion of an operating mine is being considered. If a statistical procedure can be found which, from exploration sampling data, produces results sufficiently close to production records, such as blasthole assays or millhead assays, and if
the mine geologists and engineers believe that it is safe to carry the procedure into the unmined part of the deposit, they may have a very useful predictive tool.

Mention should be made of the accuracy with which the mining engineers at many operating properties are able to predict the grade which will be mined over a year's time. It would be extremely difficult to exceed their accuracy by any method. Unfortunately, in some instances, the agreement between predicted and achieved grade at the end of the year is the result of following a mining policy designed to make certain the results do agree at year end, regardless of whether mined grade could have been higher or whether higher unit production costs may be incurred in next year's operations. Achievement of a predicted grade becomes the engineer's objective rather than achievement of the highest possible grade.

The ore reserve estimator might also consider adjusting the discount rate upward to take uncertainty into account, but one question comes to mind immediately: by what percent the discount rate should be raised if, for example, it is believe that an estimate may be in error by 0.10 percent nickel in a nickel laterite with an estimated grade of 1.75 percent nickel. It would seem that a better approach is to use sensitivity analysis to determine the effects on annual cash flows of such possible errors. If the level of uncertainty in the annual cash flows due to the possible range of error is unacceptable, the company must weigh the cost of additional sampling against the possible marginal contribution of the sampling to reduction of uncertainty. An additional four or five drill holes can often be completed in a short time at a very low incremental
cost per pound of metal in ore. For example, R. B. Fulton (1970, p. 8) vice president of Newmont Mining Corporation, has quoted the cost of exploration of the Vekol Hills copper deposit in Arizona during the years 1965-1967 at 0.15¢ per pound of copper in ore. This cost includes the cost of many drill holes. On the other hand, there is a definite limit to the amount of useful information that can be gained by drilling.

Commodity Prices

In the first section of this chapter, the high degree of uncertainty attending metal price projections is discussed. It is strongly contended there that the risk involved can be traced directly to buyers and sellers, to government policy makers, and other people whose behavior is not deterministic. Insofar as this contention is true, the difficulties involved in developing accurate predictive models through techniques of statistical inference are staggering.

A fine discussion of some of the difficulties has been presented by R. L. Randall (1970) of Kennecott Copper Corporation. H. M. Jacob (1970), president of Inspiration Consolidated Copper Company, has underscored the difficulties of making projections based on historical growth rates.

Metal price projections and estimates of the degree of risk involved in projections based on methods of statistical inference are generally not to be relied upon since it is virtually impossible to take into account in the statistical procedures many of the factors which have so much influence on marginal supply and demand. One should not put blind faith in projections based on statistical inference no matter how credible they seem.
Sensitivity analysis is useful in this area from the point of view that for any assumed degree of uncertainty in a commodity price estimate one can determine the corresponding uncertainty in profitability. The sensitivity analysis does not estimate the degree of uncertainty in the price. This is still a subjective estimate.

Perhaps the safest procedure in mine valuation, and one which is very widely used, is to estimate profitability at a conservative metal price, hopefully a price that has little downward risk. Thus, copper projects are often valued today at prices in the 40¢ per pound to 45¢ per pound range, and companies feel much safer if a project will make a satisfactory return at 38¢ per pound.

Four years ago one domestic mercury producer was using a price of $425 per flask of mercury in ore reserve estimates. Expansion of a mine was planned on that basis. In the late spring of 1970, in the wake of announcements on mercury pollution, the price dropped past the $425 per flask price and currently is under $300 per flask. This is a good example of the unpredictability of many commodity prices. Tungsten and silver provide other examples.

Regardless of the method of risk analysis a company employs, its projections of metal prices are likely to be more accurate if its staff studies carefully the writings, speeches, and actions of the principal men in the commodity markets and government policy makers who influence the rules of the market. A company must also keep abreast of technologic developments that are early warnings of new uses for its products, or of complementary or substitute products.
One final point should be made. It does not seem advisable to use a very conservative sale price, say 38¢ per pound of copper for a project in the western United States, and then in addition require a very high DCFROI, for example, 20 or 25 percent.

Operating Costs

Normally a team of experienced engineers can do a very good job of estimating operating costs, particularly where standard mining and milling methods are being employed. Such engineers will also have a good knowledge of possible ranges of variation of costs about the expected cost. At one large mine in the western United States in 1968 to 1970, over 100 million tons of rock were mined at a cost only about one percent off the estimated cost.

With this kind of skill and with good cost records available, one can hope for reasonably good estimates of the risk involved in a mining cost estimate through statistical inference and probability methods, even though the basic problems with the applications of the methods are still present. The validity of the estimates will only be as good as the assumptions made about possible changes in costs of labor and materials. An interesting question is whether the use of statistical methods would have resulted in a better estimate of mining costs than that made by the engineering staff using normal procedures in the example cited above.

One might consider use of risk-adjusted discount rates in evaluating the effect of uncertainty in operating cost estimates on profitability of a project, but the case against such a practice is particularly strong here. If expressed uncertainty in an operating cost estimate cannot be traced to some specific source, it may be that it is not really too serious.
If it can be traced to a source, expenditures should have been allowed for precautionary measures in cash flow estimates. This has already been discussed. It seems far better to make explicit allowance in the cash costs of a project for sound maintenance programs, for margins of safety in ground support, for driver training programs, and so forth, than arbitrarily to raise a discount rate.

Nothing more need be said about sensitivity analysis, other than that it is useful in studying effects of possible variations in operating costs as in other areas.

Metallurgy

When the metallurgical process planned for a mining project is well known and the ore and gangue mineral suites do not include some perverse member or some common member occurring in a perverse manner, risk in the sense of variability in recoveries and concentrate grade can often be estimated quite well. Thus, the possible variability in profitability attributable to these factors can also be estimated, either by sensitivity analysis or more sophisticated techniques.

Statistical and probability methods may yield very useful results in these situations. One is dealing with physical properties of ore minerals and reagents, with physical and chemical reactions. However, no method of risk analysis can anticipate situations, such as mentioned previously in the example of molybdenite ore from the Storke level at Climax. Such processes as heap and dump leaching and the leach-precipitation-flotation process have been demonstrated to be attended by considerable uncertainty in recoveries. For heap and dump leaching, the physical and chemical processes at work are not well understood, or at
least are not very easy to control. Moreover, it is very difficult, if not impossible, to extrapolate laboratory test data to "dump-size" situations. At this stage in the understanding of dump and heap leaching, probabilistic models of recovery rates are not very credible.

It would seem to be wise to develop as accurate and detailed a cash flow model as is reasonably possible and then determine what degree of variation, for example, in recovery rates, would result in an unacceptable level of profitability. One can then ask the metallurgists how probable it is that things will actually go that badly. If the experience of the metallurgical staff will not permit them to give an answer with confidence, no amount of statistical analysis can be of much help.
DEVELOPMENT AND REVIEW OF EXPLORATION POLICY

The firm considering entrance into primary mineral production and the mining firm wishing to extend its life as a mining firm need a practical, low-cost method of determination of the types of mineral deposits which would meet the firm's investment standards and of determination of which of the deposits of the acceptable investment types can be found at a reasonable cost. Any rational exploration policy must be based on a sound study which has made these two determinations. This is true regardless of whether a firm plans on an active exploration program or on use of a limited number of highly skilled agents to seek out attractive acquisitions or joint ventures. It is true regardless of whether an exploration program is to be aimed at restudy of previously or currently producing mining districts or whether it is to consist largely of raw regional reconnaissance.

The problem of determining which countries will be explored will not be discussed in this dissertation. In the rest of this section, it will be considered that exploration management has decided to limit its activities to the United States. A completely equivalent type of analysis would be applied to any other country of possible interest. A procedure is developed in this chapter for making the two determinations mentioned above as essential to sound exploration policy making.
Procedure

The procedure consists of four phases: development of a data base; economic analysis and screening; design of exploration programs; and ranking of targets. Development of a data base consists of gathering all required geologic, production and cost data, classification of possible deposits into a manageable number of economic types, and preparation of summaries of company investment criteria and mineral commodity requirements.

Economic analysis and screening aids in identification of the types of deposits which, as operating mines, would be satisfactorily profitable. Design of exploration programs for acceptable types of deposits includes summaries of exploration methods applicable in the search for each type and costs of those methods. Ranking of targets is accomplished through a synthesis of information on costs of exploration, likelihood of discovery, and financial parameters of the types of deposits which have survived to the ranking stage.

Development of a Data Base

Figure 1 illustrates this phase.

Step 1. Gather geologic and production data for the ore deposits presently mined or mined in the past. If a country with little or no relevant mining history were under consideration, data from other countries with production histories would have to be used, but with caution. Geologic data of particular interest are size, shape, thickness, and orientation of ore bodies, and ore types. Production data of interest include the length of time required to bring the deposit into production, production rates attained, grade of ore, percentages of mineral content
GATHER GEOLOGIC AND PRODUCTION DATA FOR ORE DEPOSITS
DEVELOP OPERATING AND CAPITAL COST DATA
DEVELOP A CLASSIFICATION OF DEPOSITS BASED ON MINING AND METALLURGICAL ECONOMICS

GATHER POST-WW II COMMODITY PRICE DATA
DETERMINE COMMODITY PRICES TO BE USED IN THE ANALYSIS
ANALYZE ANY STRONGLY CYCLICAL PRICE BEHAVIOR TO DETERMINE DESIRABILITY OF FURTHER STUDY OF COMMODITIES EXHIBITING SUCH BEHAVIOR

PREPARE SUMMARY OF INVESTMENT ACCEPTABILITY STANDARDS

PREPARE PROJECTION OF QUANTITIES OF MINERAL PRODUCTS TO BE PURCHASED ANNUALLY AND COSTS OF THE MINERAL PRODUCTS ON A YEARLY BASIS

ECONOMIC ANALYSIS AND SCREENING

Figure 1. Development of Data Base
recovered in mining and milling or processing, productive life, depths at which ore was mined, mining and milling or processing methods, and coproducts or byproducts.

Step 2. Develop operating and capital cost data for the deposits to be analyzed. Costs required for proper economic analysis include development costs, required investment in plant and equipment and operating costs. Operating costs include direct expenses of mining and metallurgical treatment and indirect expenses, such as general and administrative expense and taxes other than federal and state income tax.

Step 3. Develop a classification of ore deposits based on mining and metallurgical economics, which in turn are based on the data developed in steps 1 and 2. Lacy (personal communication) is the first geologist whom the writer heard discuss this type of classification of ore deposits for use in determining exploration policy.

Uranium deposits might be classified as open pit, underground strata-bound, vein, in situ leaching or heap leaching. Uranium has also been recovered from pegmatites and lignite in the United States but not enough to merit consideration.

Copper deposits might be classified as:

- **bulk, low-grade**
  - Mission, Bagdad, San Manuel, and Sierrita deposits in Arizona; the porphyry coppers

- **mesothermal replacement**
  - Superior, Arizona, mine of Magma Copper Company; often in limestone

- **strata-bound**
  - Nacimiento mine, Cuba, New Mexico; red-bed coppers

- **pyrometasomatic**
  - Bluestone and Ludwig mines, Nevada
vein Anaconda, Blue, and Steward vein systems, Butte, Montana

heap leach Bluebird and Zonia mines, Arizona

Within most of the uranium and copper deposit classes there is considerable variation in size.

Gold deposits might be classified as:

bulk, low-grade Carlin and Cortez mines, Nevada

large, pipelike replacement ore bodies Homestake mine, South Dakota

relatively small but high-grade veins and pipes, such as most epithermal veins and near-surface enriched portions of mesothermal veins King of Arizona and Vulture mines, Arizona

large veins, pipes, mantos, and irregular bodies Camp Bird vein, Colorado

placers Sierra Nevada, California

The purpose of this classification is to make the economic analysis phase a reasonably manageable task.


Step 5. Determine commodity prices to be used in the analysis.

Step 6. Analyze any strongly cyclical price behavior to determine desirability of further study of commodities exhibiting such behavior.

The characteristics of some types of deposits coupled with strongly cyclical price behavior could result in an undesirable or at best highly unpredictable contribution to earnings per share.
**Step 7.** While the above data preparation is going on, the exploration policy makers should have prepared (1) a summary of investment acceptability standards and (2) a list of projected mineral product requirements and expected costs of such requirements for years within the firm's long-range planning horizon.

If the firm would differentiate for investment purposes between deposits to produce a new product for sale and deposits to provide a captive source of materials already purchased in quantity by the firm, summaries of investment standards for both types of deposits should be prepared.

**Economic Analysis and Screening**

*Figure 2 (in pocket) illustrates the process of economic analysis and screening.*

**Step 1.** Prepare graphs showing revenues and operating costs for each class of deposit. If data are available from operating mines it should be used. If no operating data are available, estimates of cost ranges can be prepared by competent engineers. Figure 3 shows revenue and cost data from the Homestake, Carlin, and Cortez mines. Figures 4 and 5 show revenue and cost data from domestic operating porphyry copper-molybdenum mines. The profit potential of the porphyry coppers is clearly indicated.

Classes of deposits with revenues per ton of ore greater than operating costs per ton by an acceptable margin should be analyzed in more depth. Deposits with revenue per ton less than operating costs per ton or with value greater than costs by an unsatisfactory margin may be rejected at this stage but may be considered later as possible lower cost
Figure 3. Revenue and Operating Cost per Ton for Three Gold Mines
Figure 4. Revenue and Operating Cost per Ton for Six Open Pit Copper Mines
Figure 5. Revenue and Operating Cost per Ton for a Block Caving and a Sublevel Caving Underground Mine
sources of raw materials for a firm than present outside sources. If a firm does not purchase the material in question in significant quantities, there will be no use in further consideration of the deposits.

**Step 2.** Prepare tables for each acceptable class of deposits which show for examples of the class production rates, margin per ton, reserves, and life at indicated production rate. The tables will indicate not only the amount of earnings available in an individual year, but also the number of years over which earnings can be expected. The importance of both of these factors is discussed in Chapter 1 of this dissertation.

**Step 3.** Analyze the deposits with acceptable value and cost relationships to determine their investment value. Financial parameters which may be estimated include DCFROI, NPV, cost per unit of product, length of payback period, rate of return on total and equity capital invested, contributions to earnings per share, or whatever other criteria management employs.

The following example illustrates the type of analysis which should be performed. Suppose it is desired to determine whether large, deep molybdenum deposits of the Henderson, Colorado, type could make satisfactorily profitable mines. Financial analyses of several hypothetical mines would be made based on varying production rates, grades, recoveries, and other variables. One such hypothetical operation could be defined by the following variables:

<table>
<thead>
<tr>
<th>molybdenum price</th>
<th>$1.72 per pound contained in molybdenite concentrates, fob mine</th>
</tr>
</thead>
<tbody>
<tr>
<td>production rate</td>
<td>30,000 tpd for 360 days per year</td>
</tr>
</tbody>
</table>
reserves and grade 324,000,000 tons at 0.45% MoS₂
life of mine 30 years
operating costs $4.25 per ton of ore milled
recovery of molybdenum 92%.

It is estimated that an eight-year period of exploration, development and construction would be required to bring such a deposit into construction after discovery of the deposit. The time pattern of capital outlays on the project in the preproduction period is hypothesized to be:

year 1 $1,500,000 exploration
year 2 $10,000,000 development and construction
year 3 $15,000,000
year 4 $25,000,000
year 5 $35,000,000
year 6 $35,000,000
year 7 $50,000,000
year 8 $50,000,000

total $221,500,000

These figures do not include capitalized interest but do include working capital in year 8.

Of the above yearly amounts it is estimated that the following amounts would be development costs deductible in the year incurred from taxable income from the company's other operations.
Deducting this $26,000,000 and $500,000 in exploration costs from the total investment leaves $194,000,000 to be depreciated. On a straight-line basis over a 30-year period, the annual depreciation deduction would be $6,467,000.

Assuming uniform annual income, the annual cash flow during the productive life without allowance for post-startup capital expenditures, would be:

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales</td>
<td>$100,321,000</td>
</tr>
<tr>
<td>Operating costs</td>
<td>-45,900,000</td>
</tr>
<tr>
<td>Operating income</td>
<td>$ 54,421,000</td>
</tr>
<tr>
<td>Depreciation</td>
<td>-6,467,000</td>
</tr>
<tr>
<td>Net before depletion</td>
<td>$ 47,954,000</td>
</tr>
<tr>
<td>Depletion</td>
<td>-22,071,000</td>
</tr>
<tr>
<td>Taxable income</td>
<td>$ 25,883,000</td>
</tr>
<tr>
<td>Federal and state income tax</td>
<td>-12,942,000</td>
</tr>
<tr>
<td>(50 percent)</td>
<td></td>
</tr>
<tr>
<td>Net income</td>
<td>$ 12,941,000</td>
</tr>
<tr>
<td>Depreciation and depletion</td>
<td>+28,538,000</td>
</tr>
<tr>
<td>Cash flow</td>
<td>$ 41,479,000</td>
</tr>
</tbody>
</table>
Major post-startup capital expenditures would be for development of new lifts. Assume that $21,000,000 will be required to be spent at the rate of $7,000,000 per year in production years 7, 8, and 9 for development of a second lift. Assume that like amounts will be spent in years 17, 18, and 19 for development of a third lift. Inflation is deliberately not taken into account since the selling price of the product is not raised over the mine's life. These capital expenditures for new lifts might be assumed to be 60 to 70 percent deductible from taxable income as incurred. These expenditures would have the net effect of lowering the cash flow to about $39,000,000 in each of the years in which the expenditures were made. The net effect of the rest of the new lift costs and other yearly post-startup costs might be to lower cash flow in each year by as much as $1,000,000.

The time pattern of cash flows, giving effect to (1) the deductability for tax purposes of mine development expenditures in the preproduction period and (2) the net effects of post-startup capital outlays on cash flows, is as follows:

<table>
<thead>
<tr>
<th>Preproduction Period</th>
<th>Net Cash Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>year 1</td>
<td>- $1,500,000</td>
</tr>
<tr>
<td>year 2</td>
<td>- $9,000,000</td>
</tr>
<tr>
<td>year 3</td>
<td>- $12,500,000</td>
</tr>
<tr>
<td>year 4</td>
<td>- $22,500,000</td>
</tr>
<tr>
<td>year 5</td>
<td>- $32,500,000</td>
</tr>
<tr>
<td>year 6</td>
<td>- $33,500,000</td>
</tr>
<tr>
<td>year 7</td>
<td>- $48,500,000</td>
</tr>
<tr>
<td>year 8</td>
<td>- $48,500,000</td>
</tr>
</tbody>
</table>
The DCFROI is approximately 14 percent.

In the above analysis no allowance is made for royalties, lease payments, or a purchase price for the property. Such payments would be made if the property were acquired from a holder of claims or leases on the property.

For the sake of clarity, recapture of exploration expenses is not considered in the above analysis and no assumptions are made about possible investment tax credits. The Prentice-Hall Federal Tax Handbook (Prentice-Hall, Inc., 1971) contains a clear discussion of the federal tax regulations dealing with recapture as ordinary income of earlier exploration cost deductions. The costs of exploring a mineral property may be deducted in the year in which they are incurred. If a property is developed into a mine, previously deducted costs of exploration of the property must be recaptured as ordinary income.

Also for the sake of clarity, the 10 percent federal tax on tax preferences is not considered. The Tax Reform Act of 1969 designates as a tax preference the amount by which depletion deduction allowable under Section 611 of the Internal Revenue Code of 1954 exceeds the adjusted basis of the property at the end of the taxable year. The tax is 10 percent of the amount remaining after deduction of the taxpayer's federal
income taxes for the taxable year plus an additional $30,000 from the tax preference item.

**Step 4.** Compare the financial parameters estimated for each of the types of deposits with the firm's investment standards for new projects. Deposits which meet the standards will then be ready for study from the point of view of exploration methods and costs and for ranking as potential exploration targets. Deposits which do not meet the firm's investment standards for new projects may be considered as possible lower cost sources of raw materials than present outside sources prior to final rejection.

If deposits do not pass the initial graphical analysis and if the firm does not purchase the material in question in significant quantities, the deposits can be rejected.

**Step 5.** For deposits which may be rejected on the basis of investment standards for new projects but which would be sources of a raw material currently purchased or to be purchased by the firm in significant quantities, compare the cost of the material from a captive mine with the cost from present sources. If the cost from the captive source is greater than the cost of material from the present outside source, the type of deposit in question will be rejected.

If the cost from the captive source is significantly lower, a "type" deposit may be evaluated as a possible investment with the relevant cash benefits being the difference in cost between the captive source and outside source. Deposits which meet the firm's investment standards for situations of this type can then be examined from the point of view of exploration methods and costs.
Discussions with executives of petroleum companies indicate that the financial attractiveness of a project to achieve a lower cost captive source of raw material will frequently be overriden by dislike of going into an unfamiliar business or by the magnitude of the commitment involved. The major "mineral commodity" used by large, integrated domestic oil companies is steel. Yet at least one major oil company has firmly decided against including iron in the list of metallic minerals for which it will search. The reason given is the enormous investment required to get into the iron and steel business. What may be overlooked is that the oil company could turn a major interest in a discovery over to an experienced integrated iron and steel company and take royalties and/or dividends which, in fact, could amount to very substantial credits against the cost of fabricated iron and steel purchases. This particular possibility deserves more attention than it has received.

Design of Exploration Programs

The design of exploration programs, in the sense of determining which exploration methods and tools are most likely to lead to discoveries, is not an appropriate subject of this dissertation. It is sufficient to say that for each class of deposit which passes the investment screening tests, a summary of exploration methods applicable in the search for the deposits and costs of the methods should be prepared. Probable time requirements for execution of exploration programs should be estimated. Finally, subjective estimates of the chances of discovery must be made.
Ranking of Targets

The economic analysis and screening provide the information needed to rank deposits on the basis of their financial attractiveness once they are discovered. Ranking for exploration department purposes also requires consideration of the probabilities and probable cost of discovery of the targets.

Establishment of Priorities in a Prospect Evaluation Plan

In the course of exploration and evaluation of a prospect, there are frequently conflicting requirements for limited resources of manpower and money. The majority of prospect evaluations take place under conditions of land tenure which impose serious time constraints on the evaluation program. Of course, it is only sound management to arrive at a realistic appraisal of a prospect by the most direct and low-cost but adequate route possible.

To accomplish his objective, which is to prove by the most direct method the existence of an orebody which will meet the profitability requirements of his firm, the exploration manager must ask himself which geologic variable on which he can gather information is likely to have the heaviest impact on profitability of the deposit. He must ask himself if the next step in his evaluation program is aimed at gathering information on this critical variable and if he will have enough information to remove the uncertainty associated with this variable when the next step is completed. Only sound judgment can provide an answer to the last of the three questions.
Geologic variables which will affect the potential profitability of a deposit include the size, shape, thickness, orientation, and structural features of the ore body, the chemical and physical characteristics of the ore and gangue mineral suites, the depth to the potential ore, and the nature of the overlying and enclosing rocks.

Drilling of a deposit may have indicated the probable existence of a tonnage of mineralized rock large enough to provide a satisfactory rate of return, but it may appear that a portion of the potential ore which must be mined in the payback period is somewhat refractory. In this situation, it may be much more important to find out just how large the refractory mineral zone is and what it is going to cost to recover the metal which may be recoverable from the refractory ores than to try to add another 10 years potential reserves to the deposit. To determine which geologic variable is going to have the heaviest impact on profitability, the exploration manager may use sensitivity analysis as discussed in Chapter 3 of this dissertation. For example, it may be assumed that the corporation with this prospect uses the DCFROI profitability criterion. For the years in which metal production will come partially from the semi-refractory ores, the exploration manager will write an expression such as the following:

$$CF_t = 2000P(R_aT_aG_a + R_bT_bG_b) - C_aT_a - C_bT_b - OC_t$$

with

- $CF_t$ the cash flow in year $t$,
- 2000 the number of pounds per short ton,
- $P$ the price per pound of the product,
- $R_a$ the percentage of product recoverable from type a ore, expressed as a decimal,
the tons of type a ore processed in the year,

the total percentage of product contained in type a ore, expressed as a decimal,

the percentage of product recoverable from type b ore, expressed as a decimal

the tons of type b ore processed in the year

the total percentage of product contained in type b ore, expressed as a decimal,

the cash cost per ton of processing type a ore,

the cash cost per ton of processing type b ore,

all other cash costs in year t

Either type a or b ore could be the semi-refractory ore.

The exploration manager can substitute the above expression for $CF_t$ in the DCFROI equation,

$$\sum_{t=0}^{n} \frac{CF_t}{(1 + r)^t} = 0.$$  

He can then enter values of $R_a$, $T_a$, $G_a$, $C_a$, $R_b$, $T_b$, $G_b$, and $C_b$ for each year in the equation, vary them within a reasonable range of values, and determine the sensitivity of the DCFROI, $r$, to such variations. The effect of such variations and comparison of the effect of such variations with the effects of increasing the life of the project give the exploration manager a good idea of whether his next activity should be aimed at gathering information on the semi-refractory ore zone which will be mined in the payback period or on the total potential reserves of the deposit. It is obvious that in many situations no such formal analysis will be necessary, but the analytical framework should be useful in evaluating many programs.
By concentrating on geologic variables in this discussion, there is no intention to relegate to a position of minor importance such factors as royalty payments, taxes, and distance to power, transportation, and water. The possible impact of the first two of these factors should normally be apparent from the outset. No project will normally be undertaken whose profitability would be seriously jeopardized by them under conditions which can be reasonably anticipated. If the availability or cost of bringing power, water, or a transportation system to the project site is seen as a possible serious impediment to profitability of the project, it certainly deserves priority in the prospect evaluation plan.
PRODUCTION FACTORS IN MINE VALUATION

Need for a Production Schedule

It would be convenient in many profitability analyses to assume that a mine would produce uniform cash receipts in each year of its life. One could avoid considerably more complicated computations of annual benefits and costs and also would only have to look up one discount factor. Unfortunately, such an assumption in many valuations results in a NPV or DCFROI which is significantly different from values of these profitability measures based on a mining plan which takes grade distribution into account.

In the first place, many deposits do not produce ores of uniform grade and metallurgical type over their lives. The grade of ore milled at Southern Peru Copper Corporation's Toquepala mine has decreased since commencement of production in 1960 as follows (Cerro Corporation, 1967, p. 20; Newmont Mining Corporation, 1969, p. 31; Newmont Mining Corporation, 1971, p. 14):

<table>
<thead>
<tr>
<th>Year</th>
<th>Grade</th>
<th>Year</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>1.732% Cu</td>
<td>1966</td>
<td>1.22% Cu</td>
</tr>
<tr>
<td>1961</td>
<td>1.667</td>
<td>1967</td>
<td>1.18</td>
</tr>
<tr>
<td>1962</td>
<td>1.507</td>
<td>1968</td>
<td>1.21</td>
</tr>
<tr>
<td>1963</td>
<td>1.370</td>
<td>1969</td>
<td>1.18</td>
</tr>
<tr>
<td>1964</td>
<td>1.342</td>
<td>1970</td>
<td>1.14</td>
</tr>
<tr>
<td>1965</td>
<td>1.290</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Norbec mine of Lake Dufault Mines Limited was brought into production in 1964. The mine produces copper and zinc concentrates with some silver and gold. The grade of ore milled has declined since 1966 as follows (Falconbridge Nickel Mines Limited, 1971):

<table>
<thead>
<tr>
<th>Year</th>
<th>Zinc</th>
<th>Copper</th>
<th>Net Smelter Value per Ton of Ore Milled</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>9.48%</td>
<td>4.84%</td>
<td>$53.75</td>
</tr>
<tr>
<td>1967</td>
<td>8.51</td>
<td>3.96</td>
<td>43.80</td>
</tr>
<tr>
<td>1968</td>
<td>3.94</td>
<td>2.03</td>
<td>21.55</td>
</tr>
<tr>
<td>1969</td>
<td>2.21</td>
<td>1.71</td>
<td>21.83</td>
</tr>
<tr>
<td>1970</td>
<td>1.82</td>
<td>1.36</td>
<td>14.46</td>
</tr>
</tbody>
</table>

The net smelter value per ton of ore milled has fallen from $53.75 to $14.46 in spite of the fact that the average selling price per pound of copper rose from 52.3¢ in 1966 to 57.7¢ in 1970. Total costs per ton were $13.93 in 1966 and $6.74 in 1970.

Stripping ratios are rarely uniform over the life of a surface mine. The size, orientation, and structure of ore bodies which must be mined underground can lead to considerable differences in dilution. Both stripping ratio and dilution contribute to nonuniformity of annual income.

These arguments may be summarized in a sentence. Uniform annual income is not a useful concept in mine valuation, except in a most superficial way. The development of trial production schedules is imperative in mine evaluation.
Selective Mining

Ordinarily it is very desirable to generate the highest possible cash flows in the early years of life of an ore body. This may often be accomplished by mining the highest grade ores in early years, even though this means that the grade of ore mined in later years will be lower than some otherwise attainable life-of-mine average grade.

The nature of metallurgical processes or the geometry of grade distribution may make high-grading impossible or unprofitable for many mines, but certain types of ore bodies lend themselves fairly readily to it. The desirability of high-grading upon occasion leads management and engineering staffs to become something less than objective in assessing the feasibility of it. There is an erroneous assumption evident in some feasibility studies that the average grade of production over a limited period, for example, two to five years, can be significantly raised, perhaps by as much as 25 to 30 percent, by selective mining. This does not pertain to evaluations in which adequate geologic evidence has been carefully marshalled to define high-grade zones and in which the feasibility of mining the zones with acceptable dilution and reasonable costs has been firmly established. It pertains instead to situations, such as that illustrated in Figure 6. The ore shown in the section is chalcocite completely replacing or coating chalcopyrite and pyrite, in other words, ore of the Morenci type.

The bulk of the highest grade enriched ores of porphyry copper deposits usually occurs in the upper part of the zone of enrichment and may be heavily counted on during the payback period. The enriched ore
Figure 6. Cross Section Showing Typical Drilling Results in an Enriched Porphyry Copper Deposit
ore may be fairly irregular in distribution, as Figure 6 is intended to indicate.

In assessing the possibility of high-grading by selective mining in a deposit such as this, the first question to be answered is whether the barren zone gradually grades into ore laterally or whether there is instead a sharp boundary between ore and waste. If it is hypothesized that there is a sharp boundary, the next problem is where to draw it. Very few geologists would relish the task of drawing the boundary with the information given. Yet they are often urgently requested to do so. An angled core hole would provide real help to the geologist in this situation.

The polygon method of reserve estimation, not to be confused with use of ore blocks based on geology, assumes a sharp boundary between ore and barren rock in geologic situations, such as shown in Figure 6. Use of geologic blocks also assumes sharp boundaries but is more logical in positioning the boundaries. Some other methods of interpolation between drill holes, such as that described by Carlson et al. (1966), will assign gradually decreasing assays to the zone between holes DDH-1 and DDH-2 and between holes DDH-3 and DDH-2, moving from holes DDH-1 or DDH-3 toward DDH-2. The assumption of a sharp boundary implicit in the polygon method is very tempting to accept, particularly since the resulting ore distribution map makes selective mining of high-grade material appear highly feasible.

Strictly on the basis of the drill hole data shown, and this is a very "lifelike" situation, no one can say which is the correct assumption. However, there is an overriding factor in these situations. The
parties financing the mining venture do not want to know how high the grade of the ore body may be. They want to know instead what grade can be reasonably expected. Put another way, they would like to have a grade estimate which reasonable geologists are quite confident will not turn out to be significantly higher than the fact. If the ore body looks good at this grade, all is well. If not, and if a sharp boundary between ore and waste would make selective mining feasible and profitable and if there is reason to believe such a sharp boundary may exist, then some angle holes must be drilled to prove it.

In light of the political environment in which many mining investments are made, it is apparent that the consequences of a significant error in prediction of grade of mill feed in the early years of a mine's life may be most serious. The seriousness is emphasized by the amount of money being invested, which may run from $300 to $500 million. The conclusion is that feasibility studies should be carefully analyzed to make sure that the cash flow in the early years is not based on a selective mining plan which, in turn, is based on inadequate geologic data or engineering analysis.

Coprodjects and Byproducts

A coproduct of a mine is a product without which the ore could not be treated at a satisfactory profit. A byproduct is a product which contributes to profits but without which the mine would still operate at a satisfactory level of profits.

An example of a coproduct is the copper produced from leach solutions at Bagdad, Arizona. As of mid-1969, about three-fifths of the gross income from Bagdad mine sales came from copper concentrate and
and about one-third from cement (leach) copper (Bagdad Copper Corporation, 1969, p. 11). The remainder was accounted for by molybdenite concentrate and silver. Now that Bagdad is producing cathode copper from the leach solutions, leach copper should become an even larger contributor to sales.

Another example of a coproduct is the molybdenite concentrate produced at the Duval Sierrita mine, Arizona.

Examples of byproducts are the cement copper produced at Silverbell, Arizona, the gold and silver of most porphyry copper ores, the magnetite and pyrite concentrates of the Lutopan mine, Cebu, Philippines, and the tin recovered at Climax, Colorado.

The distribution of byproduct and coproduct minerals, just as the distribution of the principal valuable mineral, is seldom uniform throughout an ore body. An ore body frequently consists of one or more zones profitably mineable only because of the occurrence of coproducts and one or more zones profitably mineable based on recovery of one metal or mineral alone. This fact leads to some interesting problems in feasibility studies and production scheduling.

Frequently when feasibility studies are commenced, the engineer responsible for developing production plans is instructed to use a certain cutoff grade in determining mineable reserves. The cutoff grade is established on the basis of considerations of minimum acceptable profits and is not a break-even grade. For porphyry copper-molybdenum ore bodies, the cutoff grade is often expressed as a percentage of copper equivalents, for example, 0.4 percent copper equivalent. What is intended is that the mineable reserves include only those blocks of ore.
whose content of copper and molybdenum will contribute at least as much pretax profit, usually ignoring the difference in percentage depletion rates, as a block containing 0.4 percent copper. Of course, the fact that a block of rock contains mineralization of a 0.40 percent or higher copper equivalent grade is not sufficient to make it ore. It only makes it potential ore. Whether or not it is ore depends on the cost of reaching it and recovering its saleable contents.

Some very considerable errors can be made if caution is not used in applying the concept of copper equivalents in ore reserve estimates. The only meaningful way to apply the concept is to divide the deposit into reasonably small volumes, compute the contribution to pretax profits of each such volume taking fully into account grades, metallurgical recoveries, and production costs, and compare the contribution of each block with the contribution of a block containing 0.4 percent copper and no molybdenum and located at the same place as the block in question. The cost of recovering a pound of molybdenum from ore containing 0.10 percent molybdenum is less than the cost of recovering a pound of molybdenum from the same ore containing 0.02 percent molybdenum, assuming the two ores are milled at the same plant.

The following example illustrates the correct method of determining whether or not the coproduct or byproduct content of a block of rock brings the metal content up to the cutoff grade established in terms of the principal constituent of the potential ore. The pre-income tax profit of a block of ore containing copper and coproduct or byproduct molybdenum is calculated as follows:
copper sales, copper in refined form
plus:  molybdenum sales, molybdenite concentrates
minus: waste stripping cost
ore mining cost
cost of milling ore to produce copper concentrate
additional cost of producing molybdenum concentrate
cost of smelting copper
cost of refining copper
cost of transporting copper
cost of transporting molybdenum
general and administrative expense
depreciation and depletion

equals: pre-income tax profit

If this expression for a block of ore with a copper assay lower than the cutoff grade and a molybdenum assay higher than the molybdenum plant cutoff grade is set up in an inequality with the same expression for a block of ore located at the same place in the deposit and with a copper assay equal to the cutoff grade and no molybdenum, most of the terms cancel. The terms which cancel are the waste stripping cost, the mining cost, the cost of production of copper concentrate, general and administrative expense, and depreciation and depletion. The inequality reduces to:

\[
\text{Block with Molybdenum} - \text{Block without Molybdenum} = \text{pre-income tax profit}
\]

This inequality must be true if the block with a copper assay lower than the cutoff grade is to be classified as potential ore.
Assume that a block of rock contains 0.35 percent copper and 0.025 percent molybdenum, that recovery of copper through to refined metal is 82 percent, that recovery of molybdenum in molybdenite concentrate is 50 percent, that the selling price of a pound of copper is $0.50 fob refinery and the selling price of a pound of molybdenum in molybdenite concentrate is $1.50 fob mine, that smelting, refining and transportation of copper cost $0.11 per pound of refined copper produced, that the cost of producing a molybdenite concentrate is $0.15 per ton of ore milled in addition to any costs of producing a copper concentrate.

The same recovery of copper will be assumed for a block assaying 0.40 percent copper, which grade will be taken as the cutoff. Actually, recovery of copper in this block would be slightly higher than recovery from the block with molybdenum because the grade of this block is higher and because recovery of a molybdenum concentrate may cause a slight loss of copper, for example, 0.1 percent of the copper content of the millheads (Hernlund, 1961).

Substituting these values in the expressions for pre-tax profits from the blocks, the inequality is as follows:

<table>
<thead>
<tr>
<th></th>
<th>Block with Molybdenum</th>
<th>=</th>
<th>Block without Molybdenum</th>
</tr>
</thead>
<tbody>
<tr>
<td>copper sales</td>
<td>$2.87</td>
<td></td>
<td>$3.28</td>
</tr>
<tr>
<td>molybdenum sales</td>
<td>.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>total sales</td>
<td>$3.25</td>
<td>=</td>
<td>$3.28</td>
</tr>
<tr>
<td>less:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cost of smelting, refining and transporting copper</td>
<td>.63</td>
<td>.72</td>
<td></td>
</tr>
<tr>
<td>cost of producing molybdenite concentrate</td>
<td>.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pre-tax profits</td>
<td>$2.47</td>
<td>≥</td>
<td>$2.56</td>
</tr>
</tbody>
</table>
Substituting these values in the inequality yields:

\[ 2.47 \leq 2.56. \]

Since this is false, the block is not potential ore at this time.

The determination of whether or not a particular block qualifies as potential mineable ore has been made without reference to the concept of copper equivalents. The concept itself is superfluous in mine planning and valuation. Worse it can be quite misleading. To make the statement, as is sometimes done, that at $0.50$ copper and $1.72$ molybdenum, the average grade of a deposit containing average grades of $0.60$ percent copper and $0.012$ percent molybdenum is $0.651$ percent copper equivalent is meaningless. Moreover, there is generally no single factor which can be used throughout a given ore deposit to convert molybdenum assays to an equivalent copper grade.

A rigorous analysis of the type described above would take into account the fact that the percentage recovery of metals from ores is a function of the quantity of metals in the ores and of the grades of concentrates which it is desired to produce.

Many byproducts which will certainly be recovered are not taken into account in feasibility studies. For example, the gold and silver of many porphyry copper ores are often not taken into account in feasibility studies for new mining projects. The copper recoverable by leaching dumps or prepared heaps of rock stripped to reach milling ore is often, probably in the majority of valuations, not taken into account. There are two good reasons for this. Neither the percentage or rate of recovery of these byproducts can be predicted with any real certainty.
Coproducts by definition are always taken into account in project valuation. Whether byproducts should be taken into account is a matter of judgment in each particular valuation.
FISCAL FACTORS IN MINE VALUATION

Mineral Commodity Prices

Measures of profitability tend to be more sensitive to changes in prices received for mineral commodities than to other variables involved in mine valuation. For example, a 1¢ per pound increase or decrease in the average annual price received by Magma Copper Company, a subsidiary of Newmont Mining Corporation, for its copper output would have increased or decreased the company's annual earnings by approximately $0.55 per share before income taxes at its production capacity in 1968 (Newmont Mining Corporation, 1969, p. 35). Magma's earnings amounted to $2.48 per share in 1968 but would have been higher except for the industry-wide strike of 1967-1968. In 1966, the year before the strike began, earnings per share were $6.47.

One of the most critical decisions in a feasibility study is the price to be used. One does not really get around the problem of choosing a price by evaluating the project at a pessimistic, most likely, or optimistic price, as is suggested by some authors (for example, Hertz, 1964). It is still necessary to select one price on which the decision to proceed with, postpone, or abandon the project will be based.

In the opinion of this writer, the price on which the decision is based should be a conservative price for the year in which production will begin. Forty cents per pound is too low a price to be using for copper in the evaluation of projects which could be starting production in five to eight years. A conservative price for copper to be used in valuation
of a mining project which would produce its first ore five years from now might lie in the 50¢ to 55¢ per pound range.

However, there is another approach to the problem which may provide more meaningful information than the difference in profitability between conservative and liberal price projections. This approach is to determine where a new project's projected cost per unit of product stands in relation to the costs of other producers. If the new project's estimated production cost is in the top 10, or even 25, percent of the range of world production costs, it may not be desirable to proceed in spite of the attractiveness of the project at current or somewhat escalated prices.

**Inflation**

A recurring question in financial analysis is whether allowance should be made for inflation of operating costs in a feasibility study and, if so, what assumptions should be made for changes in commodity prices. These questions are fostered by such facts as, for example, that the costs of certain underground mining operations are currently rising at a rate of 7 to 8 percent per year. The costs of a number of items of equipment, such as certain hoists and trucks, have risen by as much as 15 to 25 percent over the last three years. There is justification for concern over the impact of such inflationary increases in costs on the viability of a project which would offer, for example, a 12 percent DCFROI at current operating cost levels.

The best practice is probably to proceed as follows. Commodity prices should be chosen which are considered to be reasonably conservative for the year in which production will commence, and they should be held constant over the life of the project. In evaluation of a proposed
block caving operation which would produce its first ore five or six years hence, a copper price of 55¢ per pound might be used. In evaluation of a proposed silver mine to be ready for production in three years, a price of $1.90 or $2.00 per troy ounce might be used. On the other hand, in evaluating a proposed gold mine with a three-year preproduction period, a gold price of $38.00 per troy ounce might be used. This price is lower than current levels.

Preproduction costs should be escalated in accord with assumed rates of inflation of costs of the labor and materials which the preproduction costs represent. From the point in time of commencement of production, costs should not be raised solely because of inflation. The reason should be clear. To allow the prices of labor and materials to rise without allowing the price of the mine's products to rise will unfairly and unreasonably force the profitability down, usually significantly, often fatally.

Learning Period Costs

The early years of life of an underground mine can provide a real learning situation for the most experienced miners. Moreover, commonly, men who have never worked underground must be trained. In Arizona today at least four major copper deposits are being evaluated which will be mined by large-scale underground methods, if and when they come into production. These include the deep Miami deposit of Miami Copper Company, the Kerr-McGee deposit near Patagonia, the Copper Creek deposit being drilled by Newmont Mining Corporation and Humble Minerals Corporation, and the Safford deposit of Phelps Dodge Corporation. In addition, Occidental Minerals Corporation is evaluating
a deposit at Miami, Arizona, which will probably eventually be mined by some caving method or leached in place after some form of ground preparation. San Manuel Copper Company is expanding the production rate at its San Manuel, Arizona, underground mine from approximately 40,000 to 60,000 tons of ore per day, and Magma Copper Company is developing large new underground reserves at Superior, Arizona.

If these potential projects are to become or, in the case of San Manuel, remain profitable mines, many more miners, engineers, and supervisors skilled in bulk underground mining methods will be needed than live in the United States today. It is not clear at this time where these men will come from, so it is likely that many men completely inexperienced in mining methods, such as block caving, will have to be given thorough and expensive training, beginning with the most basic principles. Many, and quite possibly most, trainees will leave after a short period of employment. The experience of Copper Range Company discussed in the beginning of this dissertation is relevant in this regard. San Manuel Copper Company was experiencing a substantial turnover rate of new underground employees in 1970.

A shortage of experienced personnel can result in higher mining cost in the early years of production than in later years when the mining characteristics of the ore body are known and seasoned, efficient crews and supervisory staffs are on the job. Mine labor costs per ton of ore produced may be twice as high in the first two years of life of a large underground mine than in the fourth or fifth years.
A feasibility study of a mining project must take into account the availability of skilled and efficient labor and the effects of learning periods on mining costs in early years of the mine's life.
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SCREENING PROCESS 1
Graphical economic analysis of each class of deposits.

ACCEPT deposits with value of ore greater than costs/tor satisfactory margin.

REJECT

Develop criteria for determining significance of purchases of metals.
sits with value/ton than costs/ton by virgin.

Investment analysis to estimate financial parameters of model deposits from each class of acceptable deposits.

Determine whether or not the metal is purchased in significant quantities.

- **NO**
  - **FINAL REJECTION**
  - **REJECT**
    - Deposits whose metal would cost more than metal purchased outside.

- **YES**
  - Compare cost of metal from captive mine with cost of metal from outside seller.
  - For deposits whose metal would cost more than metal purchased outside.
SCREENING PROCESS 2

Compare estimated financial parameters with investment desirability criteria for new projects.

REJECT
Deposits which do not meet standards for new deposits.

For deposits whose metal would cost less than metal purchased outside, evaluate investment in mine with relevant cash flows.
SCREENING PROCESS 2
Compare estimated financial parameters with investment desirability criteria for new projects.

REJECT
Deposits which do not meet standards for new deposits.

Deposits with acceptable financial parameters go into the RANKING PHASE.
Develop criteria for determining significance of purchases of metals.
Determine whether or not the metal is purchased in significant quantities.

**NO**

**FINAL REJECTION**

**YES**

Compare cost of metal from captive mine with cost of metal from outside seller.

**REJECT**

Deposits whose metal would cost more than metal purchased outside.

**REJECT**

For deposits whose metal purchased outside is being cash-saving difference.

**REJECT**

Deposits which do not meet criteria for this type of investment.

**FIGURE 2 ECONOMIC ANALYSIS AND SCREENING**
REJECT

Deposits which do not meet standards for new deposits.

For deposits whose metal would cost less than metal purchased outside, evaluate investment in mine with relevant cash flows being cash savings resulting from cost difference.

REJECT

Deposits which do not meet criteria for this type of investment.

Deposits which meet criteria for this type of investment now go into the RANKING PHASE.

ANALYSIS AND SCREENING
REJECT
Deposits which do not meet standards for new deposits.