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Economic Comparison of Mineral Exploration and Acquisition Strategies to Obtain Ore Reserves

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An analytical framework is formulated to assist mining companies in assessing the relative merits of mineral exploration and acquisition strategies. The anticipated costs, risks, and returns of each strategy are conceptualised using decision trees. Economic criteria — expected net present value, expected return per unit of investment, and the probability of success — for each strategy are derived from the appropriate decision tree network. Application of the analytical framework is illustrated using the example of a medium-size company in the Canadian base metal sector.

Introduction

Each company which is active in the mineral sector has objectives, finite resources, strategies, and an organisational structure. It operates within a complex economic, social, and political environment.

Economic mineral deposits - initially unknown and subject to depletion during mining - are central to mining company planning. A mining company's ability to realise its objectives in the long term depends on its ability to obtain economic deposits. Thus, the development of ore reserves is a key planning issue.

Two basic strategies are available to the mining company for ore reserve replacement and growth:

- discovery and delineation of economic mineral deposits through successful exploration;
- purchase of economic mineral deposits through a successful program of deposit acquisition.

Cook (1983) has analysed the historical record of exploration and acquisition to determine the relative importance of each strategy. Table 1 summarises his findings for 70 "world class" deposits discovered since 1950. The relative importance of exploration and acquisition for 15 large mining companies in existence from 1900 that have controlled 141 "major" mineral deposits is outlined in table 2. Finally, table 3 shows the classification of 45 "major" deposits obtained by 9 energy companies since 1975.

The main time trends apparent from Cook's analysis are as follows:

- 1900 to 1950 was mainly a period of acquisition by the mining industry, resulting in the development of most of today's large mining companies;
- 1950 to 1975 was mainly a period of exploration which represented the primary method of growth by these

TABLE 1

Relative importance of exploration and acquisition:
70 world class deposits discovered since 1950

Region	Number of Deposits	How Deposits Were Obtained			
		Exploration		Acquisition	
		Number	Percent	Number	Percent
Africa	8	7	88	1	12
Australia	8	8	100	-	-
Canada	14	8	57	6	43
Latin America	12	4	33	8	67
United States	22	18	82	4	18
Other	6	4	67	2	33
Total	70	49	70	21	30

Source: Cook (1983)

TABLE 2

Relative importance of exploration and acquisition: 141 major mineral deposits controlled by 15 large mining companies in existence since 1900

Company	Number of Deposits	How Deposits Were Obtained			
		Exploration		Acquisition	
		Number	Percent	Number	Percent
Anglo American	13	-	0	13	100
BHP	4	-	0	4	100
Phelps Dodge	7	-	0	7	100
Noranda	17	2	12	15	88
Rio Tinto Zinc	9	2	22	7	78
Gold Fields	12	3	25	9	75
Inco	8	2	25	6	75
Amax	7	2	29	5	71
Newmont	14	4	29	10	71
Homestake	6	2	33	4	67
Cominco	12	5	42	7	58
Western Mining	7	3	43	4	57
Asarco	16	7	44	9	56
Placer Development	6	4	67	2	33
Freeport-McMoran	3	3	100	-	0
Total	141	39	28	102	72

Source: Cook (1983)

TABLE 3

Relative importance of 45 major mineral deposits controlled by 9 energy companies since 1975

Energy Company	Mineral Company Acquired	How Deposits Were Obtained			
		Exploration		Acquisition	
		Number	Percent	Number	Percent
Amoco	Cyprus	-	0	4	100
Atlantic Richfield	Anaconda	-	0	6	100
BP	Selection Trust	-	0	5	100
Fluor	St.Joe	-	0	12	100
Pennzoil	Duval	-	0	4	100
Sohio	Kennecott	-	0	5	100
Union Oil	Moly Corp.	-	0	2	100
Exxon	-	1	33	2	67
Getty	-	4	100	-	0
Total		5	11	40	89

companies. With increasing competition, the supply of mineral properties dwindled. Thus, mining companies were encouraged to establish exploration departments to maintain their growth;

- 1975 to the early 1980s was a more recent period of acquisition. Energy companies which entered the mining business at this time primarily did so through the acquisition of mining companies.

Cook's findings also highlight differences in ore reserve strategies among large mining companies. Some companies have been primarily successful through mineral exploration. Others have prospered by acquiring known mineral deposits.

The importance of the ore reserve issue within mining companies, historical time trends, and the wide range of corporate experiences observed, suggest that more attention should be devoted to objectively assessing and comparing the economic attributes of mineral exploration and acquisition strategies. The purpose of the paper is to help structure the thought process along these lines. The intention is to assist decision making within mining companies and their interdisciplinary corporate planning groups.

Mining company setting

The mining company's planning process, portrayed in figure 1, consists of:

- setting objectives;
- developing corporate resources;
- channelling resources through strategies to areas of environmental opportunity;
- evaluating, selecting, and implementing the investment alternatives identified.

Interrelationships among objectives, resources, and environmental conditions guide the formulation of corporate strategies.

Mining company objectives are similar to those of other companies - profit, growth, and survival. Profit is generated by the

company mining and selling minerals at prices which at least cover the time-adjusted initial investment and subsequent operating costs. Profit can also be realised by the sale of mineral deposits. Growth follows from the company's success in generating and reinvesting profits. Survival is a necessary precondition for both profit and growth. Mining converts the company's finite and exhaustible ore reserves into cash and other assets. To survive, the company must successfully invest part of these new resources in replacing the depleted ore reserves. An underlying thread among the profit, growth, and survival objectives is ore reserve replacement and growth.

Financial, human and capital resources are invested by the mining company to realise its objectives. Financial resources have varying degrees of liquidity. Existing liquid resources are important for current budgeting. For longer term financial planning, the potential to raise equity and debt funds is critical. Increases in the asset base of the company through the addition of economic mineral deposits boost the company's borrowing

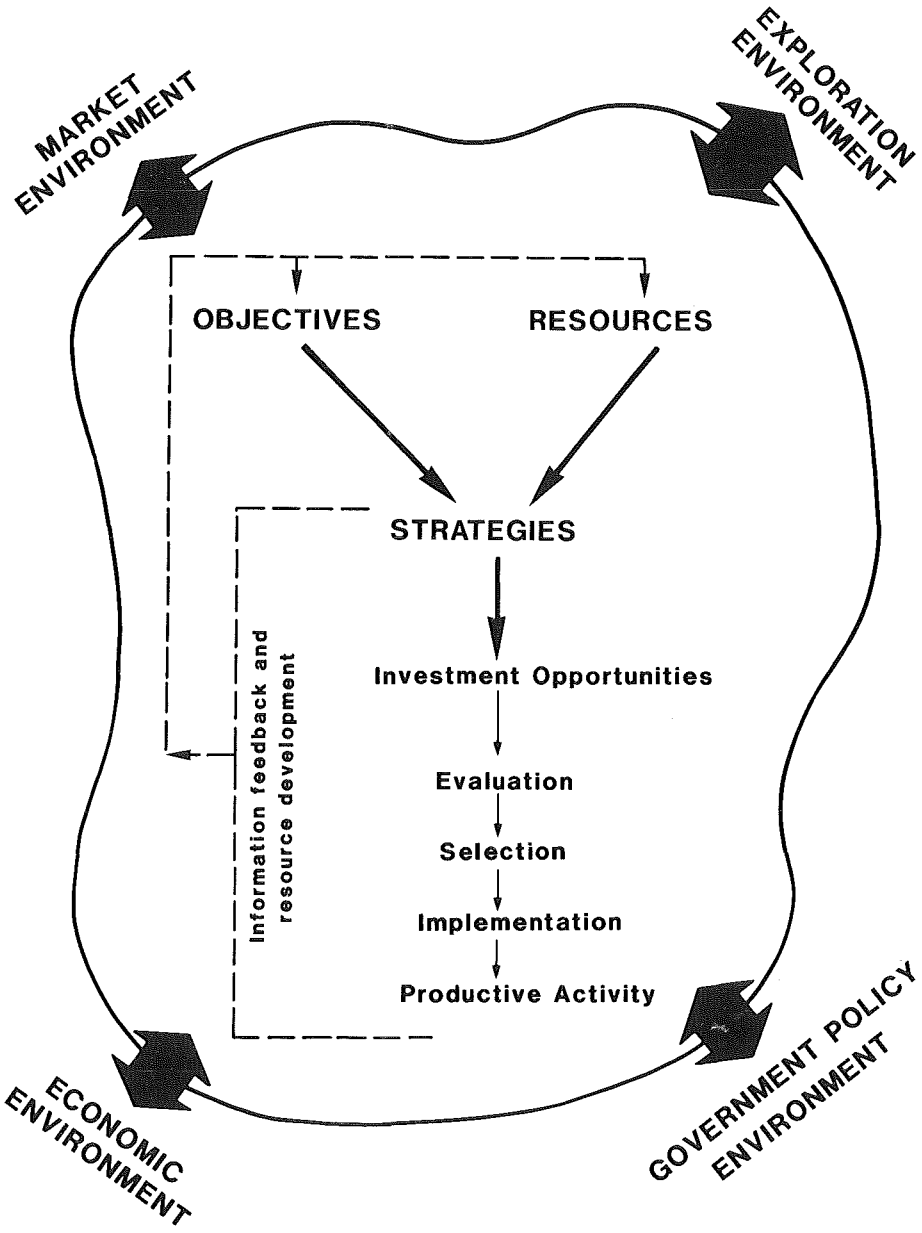

FIGURE 1. Mining company planning framework

capability as well as its attractiveness to new equity. Human resources, including managerial and technical skills, have a strong influence on the strategies adopted. As a company evolves, the range of skills employed widens, and internal structures and procedures form around these skills. Capital resources consist of the company's fixed assets and productive facilities. The most important capital resource is the company's stock of ore reserves, its basic source of earnings. Ore reserves must be replaced at least as fast as the rate of depletion for the company to sustain its existing productive capability.

The mining company operates in a changing environment which must be subject to on-going review. Interaction between the environment and the company is critical to the formulation of corporate strategies. Changes in environmental conditions may result in changes of strategy and changes to the company structure. Selected elements of the mining company's environment are:

- mineral market environment including worldwide supply-demand-price relationships and competitive position;
- economic environment including business cycles, inflation and exchange rates, external sources of funds, and the availability of human resources;
- government policy environment which provides important opportunities and constraints for corporate planning;
- mineral exploration environment which yields the ore reserves necessary for corporate profit, growth and survival through the discovery and delineation of economic mineral deposits.

The corporate planning function within mining companies may be summarised by one essential question - how should the company invest its financial, human and capital resources within these environmental conditions to best realise its profit, growth, and survival objectives?

The acquisition market

The discovery and delineation of economic mineral deposits is the ultimate source of ore reserves. However, there is a degree of interdependence among various types of companies in the mineral sector. This interdependence gives rise to acquisition opportunities.

At the outset, it is necessary to define what we mean by the term "acquisition". Different types of mineral opportunities may be acquired - mining companies, operating mines, mine development opportunities, exploration projects, and mineral rights. Mining company acquisition is really a mixture because it normally includes obtaining both mineral deposits and an exploration team. As the focus of attention shifts from operating mines to mineral rights, the exploration component increases. At the end of this range, acquisition of mineral rights is not much different than exploration itself.
To keep the distinction between the two strategies as clear as possible, this paper defines "acquisition" as obtaining ore reserves which have been found and partially delineated, at or near the mine development decision point.

The acquisiton market comprises the supply of and demand for mineral deposits. Acquisition occurs when a mutually agreeable price is negotiated for the transaction.

Mining companies have different objectives, strengths, and weaknesses. Under conditions of uncertainty, companies will inevitably have varying perceptions of geological potential, market outlook, capital and operating costs, recovery and

dilution factors, and government policy outlook, pertaining to the valuation of particular mineral properties. These factors explain the existence of an acquisition market for ore reserves.

The basic reason why acquisition transactions take place is that particular mineral deposits are perceived to be of lower value to the seller than to the purchaser. The position of acquisition within the mineral sector is portrayed in figure 2. The supply of acquisition opportunities is derived from the discovery of mineral deposits which are perceived to be economic for some company in the industry. Many of these are of course developed and mined by their discoverers. The remainder are available for acquisition. A seller may dispose of a mineral deposit through an outright sale, a joint venture agreement, or a carried interest payment. The ownership of some deposits may change more than once before their ore reserves are depleted through mining.

Reasons for the transfer of mineral deposits among companies include both actual and perceived differences in economic value. The seller may lack the skills, technology, or regional infrastructure necessary for profitable exploitation. Insufficient funds may be available to develop the project and, in

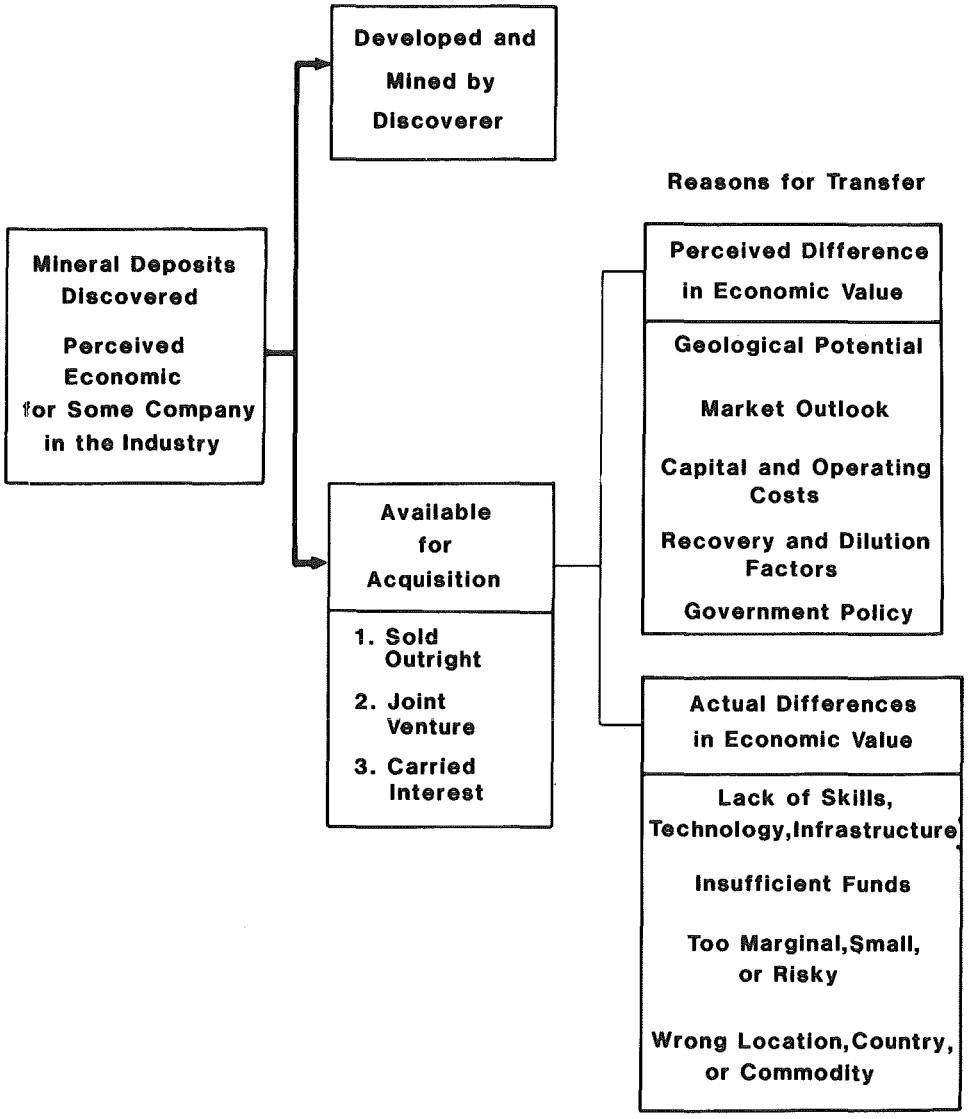

FIGURE 2. The supply base for acquisition

some cases, a company may be forced to liquidate its ore reserves for survival purposes.

A mining company may sell a deposit because it does not fit the corporate plan. It may be considered too marginal, small, or risky. Alternatively, the deposit may occur in the wrong location or country, or it may produce commodities which do not fit the company's current marketing strategy.

Delineating the economic parameters

All large mining companies explore and acquire ore reserves. Therefore, the issue is one of strategic emphasis. As Cook's work highlights (table 2), there is a wide range of mining company experiences in this respect.

The relative attractiveness of the mineral exploration and acquisition strategies depends on their respective cost, risk, and return characteristics. These parameters are combined in the evaluation process to assess overall economic criteria. Initial delineation of the respective cost, risk, and return parameters follows.

Costs

Exploration

The physical occurrence of mineral deposits in nature and the demand for mineral commodities in the economy provide the basic stimuli for mineral exploration. Favourable perceptions of exploration geologists and market researchers regarding these factors are combined to guide the selection of environments for exploration.

Mineral exploration is a sequential information-gathering process comprising two main stages - primary exploration and delineation. In the primary exploration stage, potentially favourable areas of land are initially selected within an environment of interest and, then, these areas are subjected to a series of geological, geophysical, and drilling tests. The successful result of primary exploration is the discovery of mineral occurrences or, in other words, the intersection of positive indications of mineralisation of potentially economic grades across mineable widths usually by drilling. This result constitutes a technical or geological success. At this stage, the ultimate size and value of each mineral occurrence is unknown.

The discovery of a mineral occurrence is usually of sufficient interest to justify at least the first round of delineation. The delineation stage of exploration consists of drilling and sampling a discovery on a systematic pattern with a view to establishing the deposit dimensions, geometry, and grade. As long as results are deemed favourable, delineation proceeds towards the extensive margins of the discovery to provide more complete estimates, and from wider to more closely spaced intervals to provide more reliable estimates.

Eventually, if drilling continues, the deposit information becomes reliable enough to provide a basis for preliminary feasibility testwork and studies, leading to a mine development decision. This result - a possible economic discovery for evaluation - represents the successful outcome of the delineation stage of exploration.

Exploration costs may be summarised as follows:

c_e = typical or average primary exploration cost associated with the discovery of a mineral occurrence;

c_d = average delineation cost per mineral occurrence discovered;

C_{ej} = primary exploration expenditure in the jth year;

g_j = number of mineral occurrences discovered in the jth year;

E_{ej} = exploration budget in the jth year;

p = probability of an economic mineral deposit given the discovery of a mineral occurrence;

E_e = average exploration cost required to find and delineate an economic mineral deposit.

$$g_j \text{ average } = \frac{C_{ej}}{c_e}$$

$$E_{ej} = C_{ej} + g_j\ (c_d)$$

$$E_e = \frac{c_e + c_d}{p}$$

Acquisition

An acquisition team with geological, mining, mineral processing, marketing, and economic evaluation skills is required to search for and identify opportunities, and to initially screen potential acquisitions. A number of deposits will be available to the mining company each year for acquisition.

For each available deposit which is deemed to be of sufficient interest to the company, an evaluation team or outside consultants are required to appraise the potential acquisition. Assessment of the economic value of the opportunity provides a basis for deciding whether or not the company wishes to bid on the deposit and, if so, to formulate an appropriate bidding strategy and limits.

There are various ways in which a mineral deposit may be acquired. A seller may dispose of a deposit through an outright sale, a joint venture, or a carried interest agreement. The final method of transfer and the terms of the agreement are ultimately determined by the nature of the deposit, the buyer's and seller's perceptions of the external environment; the relative strengths and weaknesses of the parties, and their negotiating skills.

Acquisition costs may be summarised as follows:

C_{aj} = cost of the acquisition team in the jth year;

h_j = number of acquisition opportunities identified in the jth year;

c_v = average cost of establishing a bid for an acquisition opportunity;

p_m = probability of making a bid given an acquisition opportunity;

B = economic value of the bid;

p_b = probability of a bid being accepted;

E_{aj} = acquisition budget in the jth year;

E_a = average cost required to acquire an economic mineral deposit.

$$E_{aj} = C_{aj} + h_j\ (c_v) + p_m\ (B)\ (p_b)$$

$$E_a = \frac{E_{aj}}{h_j\ (p_m)\ (p_b)}$$

It should be noted that there is a direct relationship between the size of a bid (B), and the probability of it being accepted (p_b).

Risks

Exploration

There are four types of risk associated with the mineral exploration strategy.

1. Discovery risk, or, the probability of an economic mineral deposit, given the discovery of a mineral occurrence (p). Due to the high discovery risk which characterises mineral exploration (typically p = .01 to .02), the application of limited organisational funds does not ensure the realisation of expected values, and exploration

resources are often expended without success.

2. Geological risk, or, the variability of the return given the discovery of an economic mineral deposit. The downside risk and upside potential associated with the variability of geological parameters among economic discoveries have important implications for exploration planning.
3. Market risk associated with the materials market for the mineral commodities ultimately produced. There is a high level of uncertainty associated with the forecasting of short-term fluctuations and long-term trends in mineral commodity prices, including exchange rate risks. The return characteristics of economic discoveries is highly sensitive to anticipated prices.
4. Project risk associated with the development to production of economic deposits. This risk encompasses the uncertainties associated with deposit-specific estimates including tonnage and grade, capital and operating costs, mine recovery and dilution factors, and mineral processing recoveries.

Acquisition

Comparable risks associated with the acquisition strategy are outlined below.

1. Availability risk, or, the probability that an economic deposit which has been discovered will be offered on the acquisition market.
2. Desirability risk, or, the probability that the company will make a bid given the availability of an acquisition opportunity (p_m).
3. Acceptance risk, or, the probability of a bid being accepted conditional on an economic deposit being available and of interest to the company (p_b). The probability of acceptance depends on the relationship between the economic value of the bid and the perceived value of the deposit, the degree of competition which exists among potential purchasers, and the negotiating power of the seller.
4. Market risk.
5. Project risk.

The latter two risks are the same as previously described for the exploration strategy.

Returns

Exploration

As a consequence of the variability in tonnage, grade, and other geological characteristics among economic deposits, there is typically a wide range of possible returns (R) distributed around the average or mean return value. The return characteristics for each possible economic discovery are determined by the estimated development and production phase cash flow characteristics. A number of measures of economic worth are derived from this cash flow distribution, including the total sales revenue generated, rate of return, and net present value. Those discoveries which satisfy minimum acceptable total revenue (size) and rate of return (profitability) conditions are deemed to be economic. The histogram of net present values for all economic deposits discovered is used to characterise the return characteristics of economic discoveries. The mean value of this distribution may be used for simplicity but, considering the wide range of returns associated with an economic deposit, there is really no such thing as a "typical" deposit.

Acquisition

The distribution of returns for economic deposits which are made available on the acquisition market is a subset of the return distribution for all economic discoveries. It is arguable whether this subset of returns is inferior or superior to the overall return distribution.

Decision tree representation

The cost, risk, and return parameters associated with the mineral exploration and acquisition alternatives for obtaining ore reserves can be best linked using decision tree networks.

Exploration strategy

The decision tree representation of the mineral exploration alternative is presented in figure 3 and summarised as follows.

1. The corporate planning horizon is N years.
2. A primary exploration expenditure of C_{ej} is invested in the jth year.
3. A number of mineral occurrences, g_j, are discovered as the result of investing C_{ej} in primary exploration. This number varies from zero to G with:

$$g_j \text{ average} = \frac{C_{ej}}{c_e}$$

4. A delineation cost c_{di} is associated with each of the i mineral occurrences discovered.
5. One of three possible outcomes results from each of the mineral occurrences delineated:
   - the discovery may be perceived as economic for the company;
   - the discovery may be perceived as uneconomic for the company but economic for some other company in the industry;
   - the discovery may be perceived to be uneconomic for all companies.

   The probabilities associated with these outcomes are p_f, p_s, and p_a respectively.

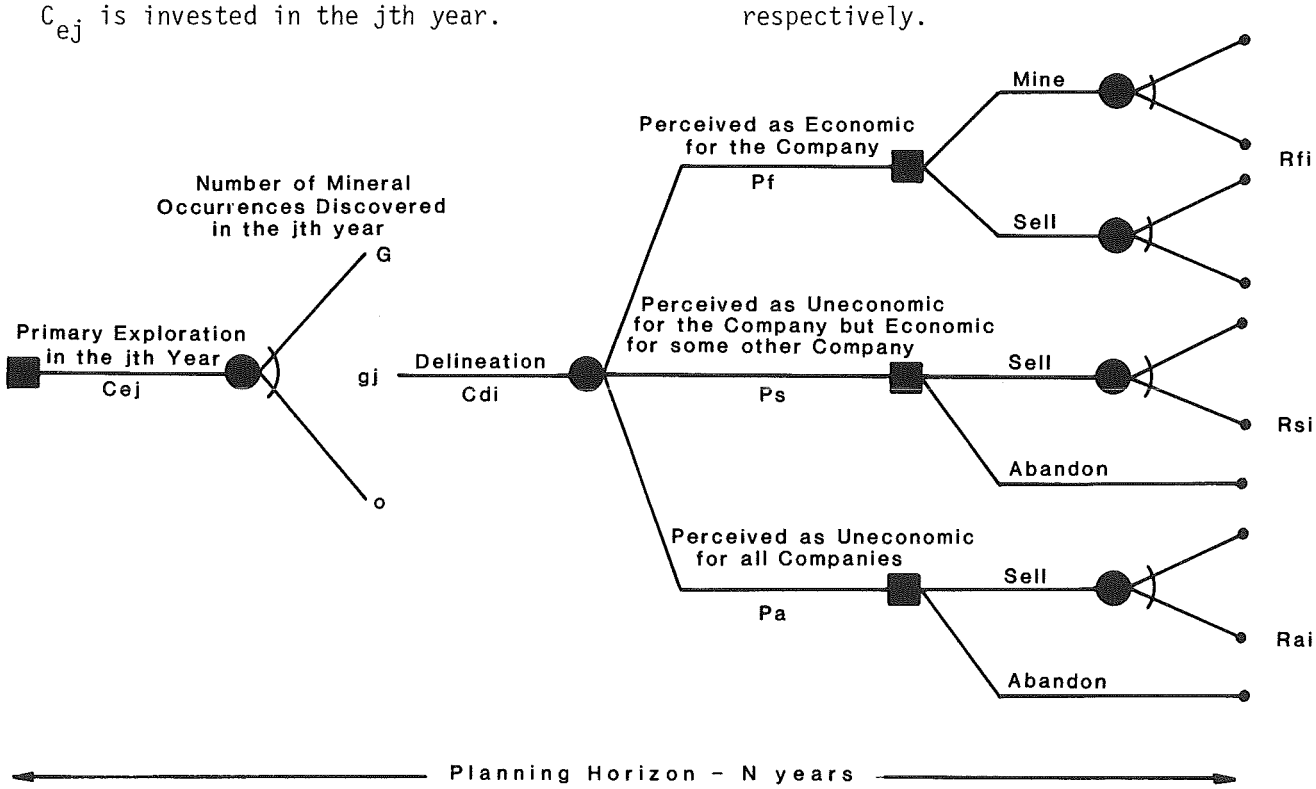

FIGURE 3. Decision tree for mining exploration strategy

$$p_f + p_s + p_a = 1$$

The probability of an economic mineral deposit given the discovery of a mineral occurrence (p generally) is p_f for the company concerned and $(p_f + p_s)$ for the industry <u>if</u> the perceptions held regarding the mineral occurrences delineated in fact prove to be correct.

6. If the mineral occurrence delineated is perceived to be economic for the company, the company decides whether to develop and mine the deposit, or to sell it. The company would consider selling the deposit if it received a bid greater than the perceived value of the discovery. A range of possible returns, R_{fi}, is associated with the mine and sell alternatives.
7. If the mineral occurrence delineated is perceived to be uneconomic to the company but economic for some other company, an attempt would be made to sell the property. Alternatively, the property would be abandoned. If the deposit is sold, a range of possible returns, R_{sj}, would be realised.
8. If the mineral occurrence delineated is perceived to be uneconomic for all companies, the company may still attempt to sell the property. If sold, a range of possible returns, R_{ai}, would be realised. However, the discovery most likely would have to be abandoned.
9. The three types of selling option represent the potential sources of acquisition opportunities.

Acquisition strategy

The decision tree representation of the acquisition alternative is shown in figure 4 and summarised below.

1. The corporate planning horizon is once again N years.
2. As depicted in figure 3, there is a probability that each economic deposit discovered will be made available on the acquisition market. Also, uneconomic deposits are offered for acquisition.
3. An acquisition team is required to search for and identify possible opportunities. C_{aj} is the cost of operating the acquisition team in the jth year.
4. Consequently, a number of acquisition opportunities, h_j, are identified in the jth year. This number varies from zero to H.
5. A cost, Cvi, is incurred to evaluate each of the i acquisition opportunities identified and to establish a bidding strategy.
6. In light of the evaluation, the company decides whether or not to bid on each of the i acquisition opportunities available. If it does not bid, the size of the bid is effectively zero. Otherwise, a bid, B_i, is offered.
7. There is a probability, p_{bi}, of each bid being accepted. In this case, the cost of acquiring the deposit is B_i. A range of possible returns, R_{bi}, is associated with the acquisition of a mineral deposit.
8. Otherwise, there is a probability, $(1-p_{bi})$, of the bid being rejected. In this case, no cost is incurred beyond the evaluation cost (c_{vi}), and no return is realised.
9. The relationship between B_i and p_{bi} is critical. As B_i is raised in relation to R_{bi}, p_{bi} increases

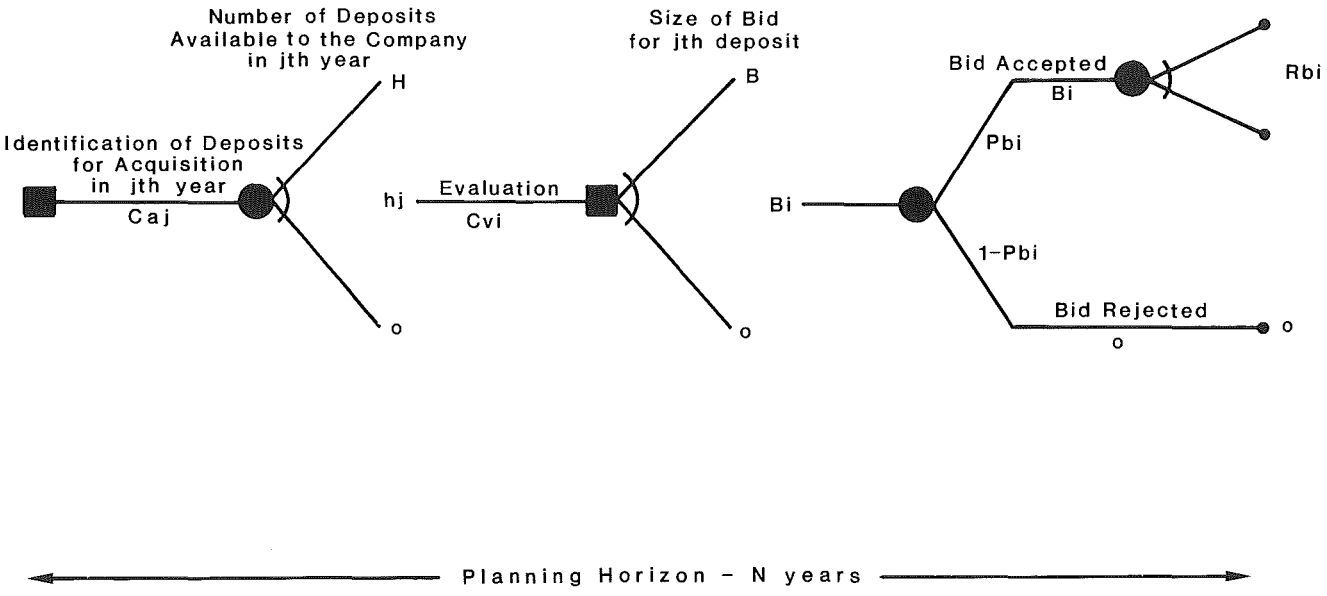

FIGURE 4. Decision tree for acquisition strategy

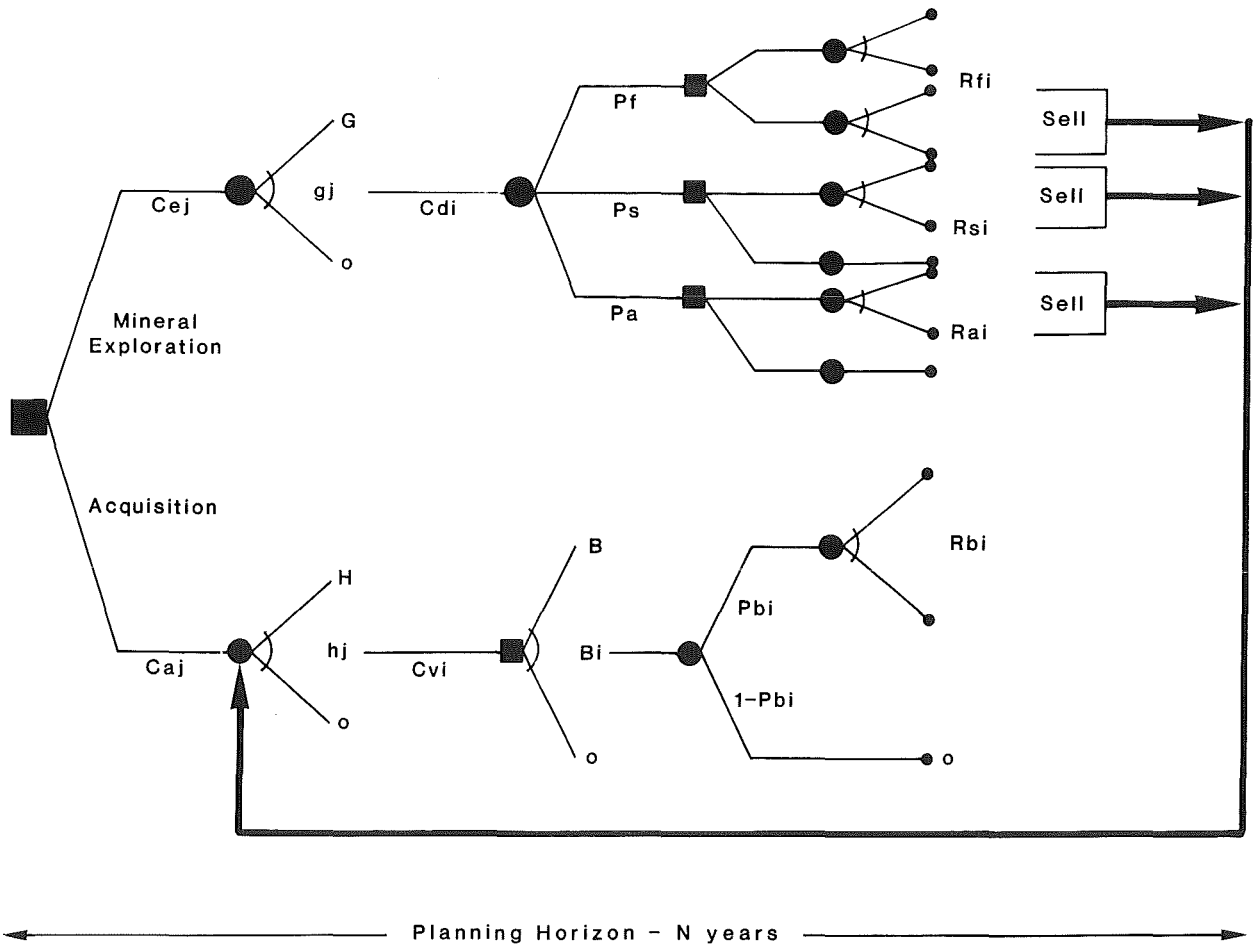

FIGURE 5. Decision tree for ore reserve strategies

towards unity.

Summary of ore reserve strategies

The decision trees for the mineral exploration and acquisition strategies for ore reserve replacement and growth are summarised in figure 5. The selling options for the mineral exploration alternative provide the basis for the acquisition strategy. The number of discoveries made in the jth year which potentially may be sold represent the acquisition opportunities which may be identified by the acquisition team.

Economic criteria

The evaluation of strategic planning alternatives should employ economic criteria relating to the mining company's objectives. Economic criteria measure the overall attractiveness of the respective ore reserve strategies. These measures are derived from the cost, risk, and return parameters related in figures 3 and 4.

The following three criteria are used in our comparison of mineral exploration and acquisition strategies for ore reserve replacement and growth.

1. Expected net present value, a measure of the profit potential of each alternative, reflecting both its size and profitability attributes.
2. Expected return per unit of investment, a profitability measure that relates expected value to the associated investment requirement.
3. Organisational risk, measuring the probability that the mining company will be successful in obtaining at least one economic deposit or, alternatively, the level of funding required to ensure success.

Expected net present value

Expected net present value assesses the average value that the respective ore reserve strategies yield in the long term, when the successes and failures associated with a very large (theoretically infinite) number of investments are considered.

Exploration strategy

The expected net present value at the start of the planning horizon of exploration activities in the jth year is:

$$\left\{ \sum_{i=1}^{g_j} p_f(R_{fi}) + p_s(R_{sj}) + p_a(R_{ai}) - c_{di} \right\} - C_{ej}$$

Thus, the expected net present value of the exploration strategy over the planning horizon of N years,

EV (Exploration Strategy) =

$$\sum_{j=1}^{N} \left[\left\{ \sum_{i=1}^{g_j} p_f(R_{fi}) + p_s(R_{sj}) + p_a(R_{ai}) - c_{di} \right\} - C_{ej} \right]$$

Acquisition strategy

The expected net present value at the start of the planning horizon of acquisition activities in the jth year is:

$$\left\{ \sum_{i=1}^{h_j} p_{bi}(R_{bi} - B_i) - c_{vi} \right\} - C_{aj}$$

Thus, the expected net present value of the acquisition strategy over the N-year planning horizon,

EV (Acquisition Strategy) =

$$\sum_{j=1}^{N} \left[\left\{ \sum_{i=1}^{h_j} p_{bi}(R_{bi} - B_i) - c_{vi} \right\} - C_{aj} \right]$$

Expected return per unit of investment

Expected net present value measures the profit potential of the ore reserve strategies. Since the strategies being compared most likely embody different investment requirements, profit is not the same as profitability - the relationship between profit and the investment required for its realisation. Thus, the strategy with the highest expected net present value is not necessarily the most profitable alternative; it may represent a larger but less profitable investment. To overcome this difficulty, the expected net present value (or, in other words, the return) associated with each strategy should be expressed per unit of investment.

The capital cost of developing an economic deposit, C_{fi} for the exploration strategy and C_{ai} for the acquisition strategy, is included with the exploration and acquisition costs to obtain the respective total investments.

Exploration strategy

The expected return per unit of investment for exploration is:

EV (Exploration Strategy)

$$\sum_{j=1}^{N} \left[\{ \sum_{i=1}^{g_j} p_f(C_{fi}) + c_{di} \} + C_{ej} \right]$$

This formulation makes the simplifying assumption that the mining company that discovers an economic deposit would develop and mine it.

Acquisition strategy

For acquisition, the expected return per unit of investment is:

EV (Acquisition Strategy)

$$\sum_{j=1}^{N} \left[\{ \sum_{i=1}^{h_j} p_{bi}(C_{ai}+B_i) + c_{vi} \} + C_{aj} \right]$$

Organisational risk

Due to the risks associated with the exploration and acquisition strategies, the application of limited corporate funds does not ensure the realisation of expected values, and resources may be expended without success. This means that there is a large difference between the average cost required to obtain an economic mineral deposit and the funds required to ensure success.

The relevant relationships are as follows:

$$P_1 = 1 - e^{-m}$$

$$A_r = - E [\ln(1-P_1)]$$

$$m = \frac{A}{E}$$

where, P_1 = probability of obtaining at least one economic deposit;

A_r = funds required over appropriate planning horizon to ensure success;

A = funds available over appropriate planning horizon;

E = average cost required to obtain an economic deposit;

e = 2.71828;

ln - natural logarithm

For example, the funds required to be 90 percent sure of obtaining at least one economic deposit are 2.3 times the average cost associated with an economic deposit:

$$A = -E [\ln(1-.90)] = -E[-2.3] = 2.3E.$$

Exploration strategy

The following exploration parameters are factored into the general organisational risk relationships outlined above.

$$A_e = N(E_{ej})$$

$$E_e = \frac{c_e + c_d}{p_f}$$

$$m_e = \frac{A_e}{E_e} = \frac{N(Eej)(c_e + c_d)}{p_f}$$

$$A_{er} = -E_e\,[\ln(1-P_1)]$$

Acquisition strategy

The following acquisition parameters are factored into the general organisational risk relationships.

$$A_a = N(E_{aj})$$

$$E_a = \frac{E_{aj}}{H_j\,(p_{bi})}$$

$$m_a = \frac{A_a}{E_a} = \frac{N(E_{aj})(H_j)(p_{bi})}{E_{aj}} = N(H_j)(p_{bi})$$

$$A_{ar} = -E_a[l_n(1-P_1)]$$

Illustrative case study

The analytical framework which has been developed is applied here to the illustrative case of a medium-size mining company in the Canadian base metal sector. Estimates are based on exploration and acquisition experience in this environment during the 1946-77 period. All values are expressed in constant 1980 Canadian dollars. Results are assessed on a potential value, before-tax basis.

During the study period, 211 significant base metal deposits were discovered in Canada. Of these, 64 became available for acquisition. According to the definition of "acquisition" adopted in this study, 42 of the deposits were confirmed as acquisitions by the mining companies concerned, and the other 22 were recognised as acquisitions using other sources of information.

Comparison of returns for economic depositions

An economic deposit for some company in the industry is defined as a discovery which generates a total revenue of at least $20 million and achieves a rate of return of at least 5 percent.

The 211 base metal deposits in the data base are evaluated for a standardised set of current economic and technological outlook conditions.

Since mineral commodity price is the most important and the most uncertain variable in the assessment, cash flows are evaluated as a function of price. Thus, for each mineral commodity, an expected price outlook is bounded by upper- and lower-limit prices.

The return characteristics for all economic deposits in the data base are averaged for comparison with the average returns for economic deposits in the acquisition sample. Comparative results are shown in table 4. The assessments are surprisingly similar. Base metal deposits which have been acquired are of at least as high a quality on average as the total population of economic discoveries.

Comparison of ore reserve strategies

The medium-size mining company used in the illustration has annual before-tax cash flows in the order of $50 million from which financing is provided for its ore reserve replacement program. The company's minimum acceptable criteria for an economic

TABLE 4

Average return characteristics for economic base metal deposits in Canada : comparison of all economic discoveries with economic discoveries obtained by acquisition

	Number		Present Value of Development Capital Cost @ 5% ($ million)	Net Present Value @ 5% ($ million)	Present Value Ratio @ 5%	Rate of Return (percent)
	Possible Economic Deposits	Economic Deposits				
Lower-Limit Prices						
All Discoveries	211	67	87	221	2.3	23
Acquisitions	64	30	95	236	2.1	22
Expected Prices						
All Discoveries	211	124	79	356	3.7	32
Acquisitions	64	47	87	427	4.1	34
Upper-Limit Prices						
All Discoveries	211	175	71	644	7.0	51
Acquisitions	64	59	88	837	8.4	56

deposit are a total revenue of at least $50 million and a rate of return of at least 10 percent. Because of limitations in the available empirical data base, a number of simplifying assumptions had to be made with respect to the analytical approach.

Estimation of parameters: exploration strategy

The following assumptions and estimates are made.

1. Assume that the company's annual exploration budget remains constant. Thus, the total exploration funds invested over the planning horizon $= N[C_{ej} + g_j \text{ average } (c_d)] = N\,[E_{ej}]$.
2. Assume: $R_{ai} = 0$; p_f and p_s are estimated on the basis of economic discoveries only (assuming that initial perceptions match the eventual reality); and that the discoveries perceived as economic for the company are developed and mined.
3. A suitable long-term planning horizon, N, is considered to be 20 years.
4. An optimum annual exploration budget of $2.5 million is used. Over the 20-year planning horizon, the present value of the exploration expenditure stream discounted at 10 percent is $21.3 million.
5. From empirical results, the average exploration expenditure required to find and delineate an economic deposit, E_e, is estimated to be $25 million.
6. The probability of an economic discovery for the industry meeting the company's minimum acceptable criteria is estimated to be 0.9 based on the historical experience. Thus, the probability of an economic discovery for the industry not meeting the company's criteria is (1-0.9) = 0.1.
7. The expected return per economic discovery retained by the company, discounted to the start of the planning horizon, R_f, is estimated to be $60.7 million. An expected development capital cost, C_f, of $13.7 million is

required to realise this return.

8. The expected return per economic discovery sold, R_s, is estimated from empirical results to be \$2.1 million. This assumes that the company would receive 20 percent of the total value when selling marginal deposits.
9. From typical base metal exploration programs, c_e = \$350,000 and c_d = \$150,000. Thus, combining these estimates, the average exploration cost associated with discovering a mineral occurrence is \$500,000.
10. The probability of a mineral occurrence being economic to the industry, p, is estimated to be 0.02.

Economic criteria: exploration strategy

1. Primary exploration expenditure in the jth year:

$$Cej = Eej\left[\frac{Ce}{Ce + Cd}\right]$$

$$= 2.5\left[\frac{0.35}{0.35 + 0.15}\right] = \underline{\$1.75 \text{ million}}$$

2. Average number of mineral occurrences discovered in the jth year:

$$g_j \text{ average} = \frac{C_{ej}}{c_e} = \frac{1{,}750{,}000}{350{,}000} = \underline{5.0}$$

3. Exploration budget in the jth year (check):

$$E_{ej} = C_{ej} + g_j \text{ average } (c_d)$$

$$= 1{,}750{,}000 + 5.0(150{,}000)$$

$$= \underline{\$2{,}500{,}000}$$

4. Total exploration funds invested over the planning horizon:

$$= N\,[E_{ej}] = 20\,[2.5] = \underline{\$50 \text{ million}}$$

5. Average exploration cost required to find and delineate an economic mineral deposit (check):

$$E_e = \left[\frac{c_e + c_d}{p}\right] = \frac{350{,}000 + 150{,}000}{0.02}$$

$$= \underline{\$25 \text{ million}}$$

6. Average number of economic deposits discovered over the planning horizon

$$= \frac{N[E_{ej}]}{E_e} = \frac{50}{25} = \underline{2.0}$$

7. Expected return per economic discovery
$= 0.9(60.7) + 0.1(2.1) = \underline{\$54.8 \text{ million}}$

8. Expected return per mineral occurrence discovered
$= p_f(R_{fi}) + p_s(R_{sj}) + p_a(R_{ai})$
$= 0.02(0.9)(60.7) + 0.02(0.1)(2.1)$
$+ 0.98\ (0)$
$= 1{,}092{,}600 + 4{,}200 = \underline{\$1{,}096{,}800}$

9. Expected net present value of the exploration strategy,
EV (Exploration Strategy)
$= 20\ [5.0(1{,}096{,}800)] - 21.3$
$= \underline{\$88.4 \text{ million}}$

10. Expected return per unit of investment

$$= \frac{\text{EV (Exploration Strategy)}}{2.0(C_f) + 21.3}$$

$$= \frac{88.4}{27.4 + 21.3} = \underline{1.82}$$

11. Probability of making at least one economic discovery over the 20-year planning horizon:

$$m = \frac{A_e}{E_e} = \frac{50}{25} = 2.0$$

$$P_1 = 1 - e^{-m} = 1 - e^{-2.0} = \underline{0.86}$$

12. Funds required over the planning horizon to be 90 percent sure of discovering at least one economic deposit:
$A_{er} = -E_e\ [\ln(1-0.90)] = \underline{\$57.5 \text{ million}}$

Estimation of parameters: acquisition strategy

The following assumptions and estimates are made.

1. The time distributions of the number of acquisition opportunities, h_j, and, consequently, the time distribution of the annual acquisition budget, E_{aj}, are impossible to predict. Thus, as was done for the exploration strategy, these parameters are assumed to remain constant over the N-year planning horizon.
2. The economic value or cost of a bid, B_i, and the probability that a bid will be accepted, p_{bi}, are also very difficult to estimate. The effect of these key parameters on the economic attractiveness of the acquisition strategy are examined for ranges of possible values using sensitivity analysis.
3. The average annual cost of operating the acquisition team, C_{aj}, based on a permanent staff of two senior employees is estimated to be $400,000. It is assumed that this acquisition team will identify an average of six acquisition opportunities each year requiring detailed evaluation of which one or two are taken to the negotiation stage.

   The average cost of evaluating each opportunity, establishing a bidding strategy, and entering into negotiations where appropriate, c_v, is estimated at $100,000. Thus, the average annual cost of acquisition and identification, E_{aj}:

   $$= C_{aj} + h_j(c_v) = 400{,}000 + 6(100{,}000)$$
   $$= \underline{\$1{,}000{,}000}$$

   Over the 20-year planning horizon, the present value of this cost at 10 percent totals $8.5 million.
4. It is further assumed that the company can expect to be successful with bids on two acquisitions over the planning horizon.
5. The average return associated with the acquisition of an economic deposit, R_b, is evaluated at $260 million, expressed as a present value at the time of acquisition. The discounted equivalent value at the start of the planning horizon depends on when the acquisition is made. Assuming that the acquisitions are made in 10 years time on average, the discounted return at the start would be $100.2 million. An expected mine development capital cost, C_a, of $20.4 million is required to realise this return.
6. The average value of the successful bid, B, is expressed as a proportion of the expected net present value of the economic deposit acquired. The following three variants are considered: 25 percent, 50 percent, and 75 percent.
7. The probability of a bid being accepted given the identification of an acquisition opportunity, p_b, is derived as follows.

   Average number of acquisition opportunities identified per year, $h_j = 6$.

   Number of acquisition opportunities identified over planning horizon, $N(h_j) = 20(6) = 120$.

   Number of bids made during planning period = 20(1) = 20.

   Number of successful bids over planning horizon = 2.

   It is assumed that successful bids result in the acquisition of economic mineral deposits.

TABLE 5

Expected return per economic deposit : acquisition in the Canadian base metal sector

Rb ($ million)	B (percent)	B ($ million)	Expected Return ($ million)
100.2	25	25.1	75.1
100.2	50	50.1	50.1
100.2	75	75.1	25.1

Thus, $p_b = 2/120 = 0.017$.

Also, note that p_m, the probability of making a bid given an acquisition opportunity = 20/120 = 0.17.

Economic criteria: acquisition strategy

1. The expected return per economic deposit acquired is assessed in table 5.
2. Results for the expected net present value of the acquisition strategy over the 20-year planning horizon, EV (Acquisition Strategy), are shown in table 6. It is anticipated that the company would be successful with bids on two acquisitions during this period.
3. Expected returns per unit of investment are summarised in table 7.
4. Probability of acquiring at least one economic deposit over the 20-year planning horizon:

$$m = \frac{A_a}{E_a} = \frac{20}{10} = 2.0$$

$$P_1 = 1 - e^{-m} = 1 - e^{-2.0} = \underline{0.86}$$

5. Funds required over the planning horizon to be 90 percent sure of acquiring at least one economic deposit:

$$A_{ar} = -E_a\,[\ln(1 - P_1)]$$

$$= -10\,[\ln(1-0.90)] = \underline{\$23 \text{ million}}$$

Comparing the exploration and acquisition results

The Canadian base metal sector is shown to offer good investment potential for companies

TABLE 6

Expected net present value for acquisition strategy : Canadian base metal sector

B (percent)	Expected Return ($ million)	Expected Acquisition Cost ($ million)	Expected Value of Acquisition Strategy ($ million)
25	150.2	8.5	141.7
50	100.2	8.5	91.7
75	50.2	8.5	41.7

TABLE 7

Expected return per unit of investment for acquisition strategy : Canadian base metal sector

B (percent)	EV of Acquisition Strategy ($ million)	Expected Investment ($ million)				Expected Return per Unit of Investment ($ million)
		Acquisition Program	B	Ca	Total	
25	141.7	8.5	50.2	40.8	99.5	1.42
50	91.7	8.5	100.2	40.8	149.5	0.61
75	41.7	8.5	150.2	40.8	199.5	0.21

wishing to pursue exploration and acquisition strategies. The return characteristics of economic deposits which have been acquired are as good if not better than the average returns associated with the total population of economic discoveries. The average return indicators for the two groupings of economic deposits are found to be remarkably similar.

The average investment associated with the exploration strategy, expressed in present value terms per economic deposit discovered, includes about $11 million in exploration expenditures, and a mine development capital cost of $14 million, totalling about $25 million.

In the case of the acquisition strategy, the average investment associated with an economic deposit, once again expressed in present value terms, includes about $4 million for operating the acquisition program, the cost of making a successful bid which may vary from $25 million to $75 million, and a mine development capital cost of $21 million, totalling $50 million to $100 million. Thus, while the up-front cost of running the acquisition program is considerably lower than the alternative exploration costs, the overall investment requirement for the acquisition strategy appears to be two to four times higher than for the exploration alternative.

The expected net present value of the exploration strategy over the 20-year planning horizon is estimated to be $88 million, as compared with $42 million to $142 million for the acquisition alternative. This is not a very meaningful measure to use in this case because the investment requirements of the two strategies are very different.

The expected return per unit of investment is perhaps the most important measure of the economic potential of the two strategic options in the long term. The expected return per dollar invested for the exploration alternative, 1.8, compares with unit returns for the acquisition strategy which vary from 0.2 to 1.4 as shown in table 7. Thus, on this basis, the exploration strategy appears to be the most economic alternative given the assumed case study conditions.

The main reason why the expected return per unit of investment is relatively low for the acquisition strategy is the high cost, B, of successfully bidding for an economic deposit. The breakeven value for B which equates the unit returns for the two strategies is determined as follows.

$$\frac{(100.2 - B)}{(4.3 + B + 20.4)} = 1.82$$

B = $19.6 million, or, (19.6/100.2)
= 20 percent

Thus, the exploration strategy would be preferred if the cost of making a successful bid exceeds 20 percent of the value of the economic deposit being acquired.

With regard to organisational risk, the probability of failure is found to be the same for both strategies: (1-0.86) = 0.14. However, the funds required over the planning horizon to be 90 percent sure of obtaining at least one economic deposit are much lower for the acquisition alternative: $23 million as compared to $58 million for the exploration strategy.

Summing up

Although the case study results presented are illustrative only, they indicate that profitable investment opportunities exist for both strategies.

The initial resources required for the exploration option are considerably higher than for the acquisition program. However, if the expected results are achieved in each strategy, substantially more investment would be required for the acquisition strategy.

While the risk of failure is shown to be the same for the two strategies, the economic loss would be more than two times higher for the exploration alternative.

The comparisons of expected values and unit returns for the two strategies is somewhat inconclusive because of the speculative nature of the estimates for several key parameters. However, exploration does appear to be the favoured strategy as it is unlikely that a delineated economic deposit could be acquired for less than 20 percent of its value.

Conclusion

The paper develops a conceptual framework to assist mining companies in assessing the relative economic merits of mineral exploration and acquisition strategies. The representation of these policy alternatives using decision trees, and the formulation of associated economic criteria, will hopefully help structure the thought process to support decision making in this important area of corporate planning.

At the working level, application of the concepts developed are dependent on meaningful empirical assessments of the associated cost, risk, and return parameters. The illustrative case of a medium-size company in the Canadian base metal sector shows that this is a more difficult matter. However, empirical studies carried out by the second author over the past 15 years (see reference list) demonstrate that this type of appraisal can certainly be made for the exploration strategy. Furthermore, there does not appear to be anything inherently more difficult about the acquisition strategy. Thus, if the same type of attention were given to the acquisition alternative, it would be surprising if similarly useful results were not forthcoming.

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