AN ASSESSMENT FRAMEWORK FOR MINERAL RESEARCH AND DEVELOPMENT: THE CASE OF THE CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY

by

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ABSTRACT

Expenditure on research and development is an investment for which a return is expected. The economic outcome of a mineral research project is greatly influenced by the interaction of broad economic, social and political forces with the innovation process in the mining industry. This interaction determines technological progress and the rate of adoption of new technology by the industry. These factors also determine the expected value of a research project and its probability of success. In a large mineral research organization, potential and existing projects compete for the resources available. The organization's research and development activities need to be coordinated and planned in order to optimize the overall result. The problem of resource allocation to mineral research projects is complicated by the high level of uncertainty associated with project outcome, the multiple purposes for which mineral research is undertaken, and the various social and organizational contexts within which mineral research is conducted.

This thesis concerns economic planning of mineral research and development activities. A conceptual assessment framework is formulated for guiding research and development investment decisions in the mineral industry. Two research and development project evaluation and selection approaches - the cost-effectiveness analysis approach and the cost-benefit analysis approach - are recommended for allocating resources to mineral research projects in a large organization. The cost-effectiveness analysis approach makes use of additive scoring models and employs the Delphi method for polling expert opinions. The cost-benefit analysis

approach employs different economic models, depending on the research project's stage. The models selected should be commensurate with the quality and quantity of data available.

The Canada Centre for Mineral and Energy Technology - Canada's largest mineral research organization - is selected as a specific case study to investigate the suitability of these approaches. The cost-effectiveness analysis approach offers clear advantages over the cost-benefit analysis approach when investment decisions are made regarding a set of research and development projects of different natures and at various research stages. On the other hand, the cost-benefit analysis approach is recommended for analysing research and development projects that require a long time commitment and a sizable amount of resources for completion.

STRUCTURE DE PLANIFICATION ÉCONOMIQUE POUR LA RECHERCHE ET LE DÉVELOPPEMENT MINIERS: LE CAS DU CENTRE CANADIEN DE LA TECHNOLOGIE DES MINERAUX ET DE L'ENERGIE

RESUME

Une somme déboursée pour un projet de recherche et de développement est un investissement qui doit être rentable. Le bénéfice économique d'un projet de recherche minière est grandement influencé par de puissantes forces économiques, sociales et politiques qui agissent de concert avec le processus d'innovation sur l'industrie minière. Ces forces déterminent le progrès technologique ainsi que le rythme avec lequel l'industrie acquière cette nouvelle technologie. Ces facteurs mesurent aussi l'espérance mathématique du rendement d'un projet de recherche et sa probabilité de succès. Dans une grande organisation de recherche minière, les projets potentiels et ceux déjà existants se rivalisent face à la quantité de ressources disponibles. Il y a donc intérêt à coordonner et à planifier l'ensemble des activités afin de tirer le meilleur parti du budget. Le problème de la distribution des fonds pour les projets de recherche minière est compliqué par le haut niveau d'incertitude quant aux chances de succès des projets, la multitude des raisons pour lesquelles les dites recherches sont entreprises et la différence des contextes, sociaux et d'organisation, dans lequels elles sont menées.

Cette étude traite de la planification économique de la recherche et du développement minier. Une structure de planification conceptuelle y est formulée pour orienter les décisions concernant les investissements pour la recherche et le développement dans l'industrie minière. Deux approches sont recommandées pour l'évaluation et la sélection des projets de recherche dans une grande organisation. Ce sont l'approche de

l'analyse coût-efficacité et celle de l'analyse coût-bénéfice. L'approche de l'analyse coût-efficacité fait usage de modèles à pointage additif et utilise la méthode Delphi pour obtenir l'opinion des experts. L'approche de l'analyse coût-bénéfice emploie différents modèles économiques suivant le stade du projet de recherche. La complexité des modèles choisis doit être commensurée avec la qualité et la quantité des données disponibles.

Le cas du Centre canadien de la technologie des minéraux et de l'énergie - la plus grande organisation de recherche minière au Canada - est choisi afin d'examiner jusqu'à quel point ces approches peuvent s'appliquer. L'approche de l'analyse coût-efficacité présente des avantages clairement définis sur celle de l'analyse coût-bénéfice lorsque l'on doit décider d'investir dans des projets de recherche et de développement de natures diverses, se trouvant à des stades différents. Par ailleurs, l'approche de l'analyse coût-bénéfice est recommandée pour l'évaluation des projets à long terme qui requièrent une quantité considérable de fonds.

To my wife Tencha
and my children:
Claudy, Rorro and
Agustín

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CHAPTER 1

INTRODUCTION

Recent economic and political changes have profoundly affected the supply of minerals and the future availability of energy sources. These changes will have a strong impact on the mining technology of the next 20-30 years. As a result, mining technology forecasting has received considerable attention and the technological trends in mining have been intensively analysed recently.

Due to the important position and role of the mineral industry in the national economies of a number of mineral producing countries, there is strong reason to believe - on the basis of present development - that the mineral industry will not decrease in importance. On the contrary, it will become more important during the next decades. This results from the fact that the demand for mineral raw materials will increase progressively, both in order to meet rising energy demands and to produce metallic, non-metallic and building materials.

The historical pattern of mineral research and development (R&D) shows a heavy reliance on the results of research in other industries. It is difficult to tell whether this pattern will change significantly in the future. There is, however, a growing awareness that greater efforts in R&D will be required to meet the future demand for minerals in a changing environment under less favourable geologic, geographic and climatic conditions.

Although all management functions must cope with uncertainty, R&D is generally agreed to be the function involving the largest number and widest range of uncertainties. Thus the R&D manager faces huge problems, not only in deciding on R&D objectives and programs, but also in defining the R&D level of effort to ensure a steady flow of technically successful projects. Basically, the R&D manager is concerned with making, by whatever particular selection technique he may favour, estimates of the following three parameters: (1) the probable costs of developing, launching and use or marketing of the innovation and the approximate timing of these expenditures; (2) the probable future income stream arising from the sale or use of the innovation and the timing involved; (3) the probability of success, technically and commercially.

If a flow of successful innovations is considered as the final output of an R&D program, then these may be measured in terms of their contribution to specific goals, in relation to their costs. The type of measurement which is relevant will vary with the level of decision-making. At the level of the firm, a great deal of detailed information will be available which can be used in project evaluation but cannot be used at a higher level of aggregation. At the level of the industry or the government it may be possible to assess external benefits and costs which are disregarded at a lower level.

Although several hundred prescriptive models already exist for the assessment of industrial R&D, these models have received very little acceptance in practice. This lack of acceptance is due to the excessive emphasis in the models on mathematical sophistication and complexity and also, in part, because these models fail to include all aspects that research managers consider important. Furthermore, research characteristics are often treated inadequately.

On the other hand, the analysis of the R&D process in the mineral industry has received little attention in the past, and the development of specific decision-making models to guide R&D investment has been undertaken by very few researchers. The mineral R&D investment decision has been examined by means of simple scoring models or expected value analysis techniques but, in the author's opinion, these models represent partial approaches to the problem. In the first place, they are designed to compare R&D projects of similar type and, secondly, they do not adequately treat uncertainty.

The various research management and budgeting systems described in the literature were reviewed by the author while employed as a mineral economist at the Canada Centre for Mineral and Energy Technology. A decision-making model was subsequently developed by the author for the assessment of the Centre's extensive mineral research activities. The author also had the responsibility of implementing this model during three consecutive fiscal years. This study summarizes the author's experience in the assessment of mineral R&D activities.

This study offers an assessment framework for mineral R&D activities designed to produce more reliable estimates for guiding R&D investment in the mineral industry. This approach makes use of the most recent developments in economic evaluation and decision-making techniques in the hope that it will produce more realistic and generally applicable results.

One of the main steps towards the development of analytical methods for the evaluation and selection of mineral R&D projects is to obtain a better understanding of the dimensions of the R&D process in the mineral industry. Chapter 2 deals with the innovation process in the mineral industry. A review of criteria by which resources are allocated to R&D is made. The factors controlling the rate of technological progress in the mineral industry and the development of industrial R&D in Canada are also discussed in that chapter. The analysis of the technical, economic, social, ecological and political factors that have influenced the innovation process in the mineral industry contributes to the advancement of the technology assessment of mineral R&D activities.

A review of the literature pertinent to the evaluation and selection methods for mineral R&D projects, along with the development of an assessment framework for the allocation of public resources to mineral research projects, are the subject of Chapter 3.

Chapter 4 outlines the role of the Canada Centre for Mineral and Energy Technology (CANMET) in planning R&D in the mineral industry and in conducting R&D within the Canadian government.

In Chapter 5 the cost-effectiveness analysis approach is applied to CANMET's Mineral Research Program as a support system for budgeting purposes. Results are presented and discussed.

Chapter 6 contains a detailed description of the cost-benefit analysis approach for mineral research projects. Two case studies illustrate application of this approach. Finally, a summary and conclusions are presented in Chapter 7.

CHAPTER 2

THE RESEARCH AND DEVELOPMENT PROCESS IN THE MINERAL INDUSTRY

The R&D process encompasses work of many different kinds and, in practice, the distinction between the two activities is often hazy. But, to generalize, research tends to be directed to the search for new knowledge while development is devoted to the capacity to produce.

On the basis of "how it is done", three categories of R&D are normally distinguished: basic research, applied research, and development. The definition of these categories is as follows: (1) basic research consists of original investigations for the advancement of scientific knowledge that do not have specific commercial objectives; (2) applied research consists of investigations that are directed to the discovery of new scientific knowledge with specific commercial objectives with respect to products or processes; and (3) development means technical activities of a non-routine nature concerned with translating research findings or other scientific knowledge into products or processes.

In order to assess the impact of the R&D process on the mineral industry, it is necessary to study the economic content of R&D as it affects society as a whole and to clarify the question of criteria by which resources are allocated to R&D.

2.1 The Economics of Research and Development

The economic nature of R&D and the economic principles governing its growth cannot be understood without examining its socio-economic content. Every R&D project is an element of a single system collecting scientific knowledge, and any form of research is connected with production and has an economic objective.

The study of the relationship between research and production is beyond the scope of this thesis. Suffice it to say that a study of this relationship requires a detailed analysis of (1) the character of the socio-economic relations of the R&D, and (2) the place and role of R&D in the process of industrial development.

The prevalence of R&D, the importance of public policy-making in the allocation of resources to R&D, and continuing discussion and debate about appropriate criteria for allocating such resources are discussed briefly in this section.

The main conclusion reached by Arrow (1962) regarding the allocation of resources to investion is that the socially optimal level will not be realized by the investment of private firms in the market. In this respect, many constraints have been mentioned: in the first place, any information obtained (for example, a new method of production) should, from a social point of view, be available free of charge (apart from the cost of transmitting information). This ensures optimal utilization of the information, i.e. that one and the same result of R&D may be used in all enterprises whenever necessary. The grave difficulties which a corporation encounters in seeking information on research supported by other corporations compel it to increase the size of its research machinery and the scope of research. This accounts for the accelerated growth of industrial R&D. A part of this growth, however, involves duplication so that substantial material and manpower resources go to waste.

The smaller the link between R&D and direct production, the less the possibility of information being marketed directly as a commodity and, consequently, serving as a source of profit.

A business firm operating in a competitive environment will seldom find it profitable to engage in a research project which is not likely to result quickly in something patentable, even if the firm can predict the nature of the research results, unless the firm keeps tight secrecy.

The force of this tendency to impose secrecy on scientific and technical information varies according to the circumstances: the nature of the information, its importance for a given company, and the character of the industry.

The argument for market failure in the production of information has to do mainly with the characteristics of information as a commodity, especially those of indivisibility, inappropriability and uncertainty (Arrow, 1962)[1]. These characteristics lead one to expect that the private sector will systematically under-invest in the production of technical information relative to its socially optimal level.

From the viewpoint of economic analysis, the high degree of uncertainty characteristic of the R&D process is an important feature. One aspect of this uncertainty is that outputs of research cannot be predicted very easily on the basis of inputs. Thus, the expected value of the process cannot be projected in advance with any degree of confidence. Furthermore, uncertainty may be expressed as the difficulty of exactly determining the time required for the production of information to solve the problem and the resources that will be spent on its solution.

Uncertainty is particularly high in basic research. Even when a specific search is underway, a high degree of uncertainty is still present. This uncertainty remains, although to a lesser degree, in the development stage. As a consequence of this uncertainty, the private firm discriminates against investment in research activities even though the expected social returns from such efforts may be very high.

Two problems arise if the government and other non-profit institutions are involved in performing industrial R&D. The first problem is related to determining the amount of resources devoted to invention. The second deals with the efficient use of these resources. The formal answer to these questions is that resources should be devoted to R&D until the

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[1] Goods or commodities are appropriables where it is possible to prevent everyone except the paying consumer from enjoying the benefit of the goods. (Arrow, 1962).

expected marginal social benefit there equals the marginal social benefit in all kinds of uses (Arrow, 1962). But the presence of uncertainty makes such calculations more difficult and tenuous than in the case of public investment decisions.

There is no way to measure by the conventions of economic accounting the separate contribution of scientific knowledge to the gross national product. One can evaluate the costs of basic science but the benefits appear in such a generalized manner that it is often impossible to separate them from those caused by other factors contributing to increased economic productivity (Johnson, 1975). However, there is some evidence of a positive relationship between inventive activity and the level of resources devoted to it.

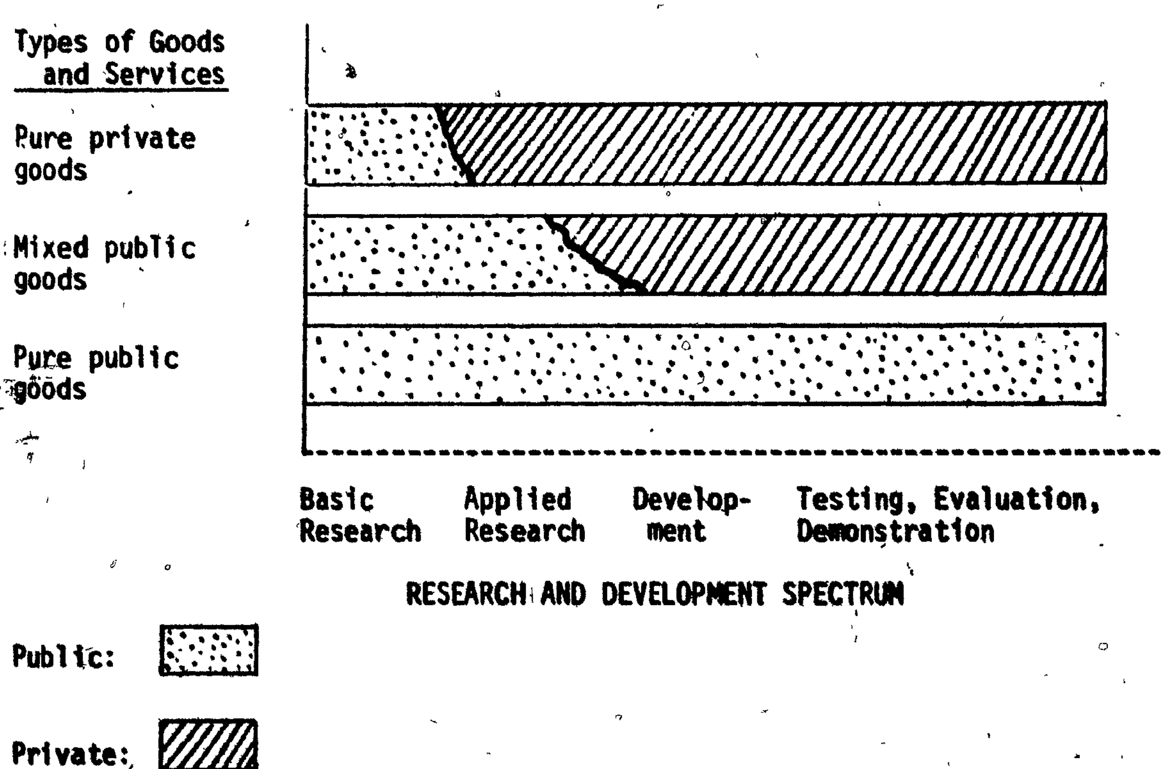
One approach to an understanding of the relation between R&D activity and economic growth via technical progress is to treat R&D activity as if it were a direct input into the productive system and to see what result emerges. The use of Cobb-Douglas production functions is suggested for this purpose. However, the difficulties involved in using Cobb-Douglas production functions to estimate the contribution of various inputs are notorious (UNESCO, 1970).

In summarizing this section, the following conclusions may be drawn. Basic scientific research constitutes that portion of the R&D spectrum which has the strongest theoretical justification for government support in the formal economics literature. The economics literature, however, offers little guidance on the overall level of budget for basic research, nor does it provide much assistance on the allocation among fields of science. On the other hand, spokesmen for the scientific community have made progress in considering criteria by which to allocate resources among sub-fields of a given scientific area, though they have yet to extend their analysis to the level of the trade-offs between physics and chemistry, for example. The scientific community has not done very much to address the problem of the appropriate overall level of support for basic science from a societal perspective, preferring instead to reason from the perceived internal needs of science.

It is clear from the literature that the question of criteria for the allocation of resources, especially public resources, to applied scientific research has received substantially less attention than that of basic scientific research. One of the major conclusions to emerge from this literature has been that a substantial growth in productivity can be attributed to the impact of research and development expenditures. The causal relationship has not been definitively established, but all evidence consistently points in the direction of R&D investment as a factor contributing to growth and productivity.

In his review of this subject, Rettig (1974), having in mind the U.S. situation, indicates the relative roles of the public and private sectors in R&D for the public, mixed and private goods (Figure 1). Where pure private goods are being produced, the public responsibility

FIGURE 1: PUBLIC AND PRIVATE SECTOR RESPONSIBILITIES FOR THE SUPPORT OF RESEARCH AND DEVELOPMENT



should be for basic research with a fairly sharp boundary between basic and more applied research. For mixed public goods, like health and agriculture, the public responsibility extends along the spectrum and the boundary should be less sharp. The public sector, finally, should be wholly responsible for R&D in support of pure public goods like national defence. In order to suggest criteria for the allocation of resources to scientific and technological research, in particular mineral R&D in the Canadian context, it is necessary to review the innovation process in the mineral industry in this country.

According to the Lamontagne Report (1972), scientific and technological activities should be appraised on the basis of the following aims which are defined as the broad purpose of society: cultural enrichment, including national prestige, economic growth and public welfare. The review of the innovation process in the mineral industry and the development of industrial R&D in Canada will be considered in the next sections from this perspective.

2.2 The Innovation Process in the Mineral Industry

The value of an R&D project is a function of three basic parameters: probability of success, net present value given a success, and the cost of conducting the R&D project. In this sense there is a strong analogy to a mineral exploration project. It is possible to apply to an R&D project a similar framework of analysis to that which has been developed for exploration planning (Mackenzie, 1972).

In most research projects, the number of possible outcomes at each research stage is large and the estimation of all the probabilities would be very difficult; a simple approximation, therefore, is clearly needed for the purpose of illustrating the value of an R&D project.

Thus, $EV = pe \times pt \times R - C$

where EV = expected value of an R&D project;

pe = probability of economic success;

pt = probability of technical success;

R = return resulting from a successful project; in other words, the difference between discounted benefits and costs (excluding C);

C = R&D project costs.

Since these parameters are usually estimated as frequency distributions to reflect variations in the value of successful projects and the multi-stage nature of the research investment process, the expected value function is modified as follows:

$$EV = \sum_i pe_i \times pt_i \times R_i - \sum_j C_j \qquad (2)$$

where $\sum_i pe_i = pe$ and $\sum_i pt_i = pt$.

These basic parameters vary significantly according to the nature of the research undertaken, and vary also with the R&D stage considered. Even more important, these parameters are affected by a number of factors, external to the innovation process itself, which determine technological progress and the rate of adoption of a new technology by an industry and consequently the expected value of an R&D project and its probability of success. Figure 2 shows the innovation process in the mineral industry as the cumulative result of economic, political and social forces and in the context of government policy and corporate organization.

In order to develop some analytical methods to guide R&D investment, an explanation of how these factors interact with the innovation process in the mineral industry is necessary. It also facilitates the definition of an optimal R&D strategy.

For the purposes of the analysis[1], an effort has been made to group individual factors into sub-categories (e.g. economic, political and

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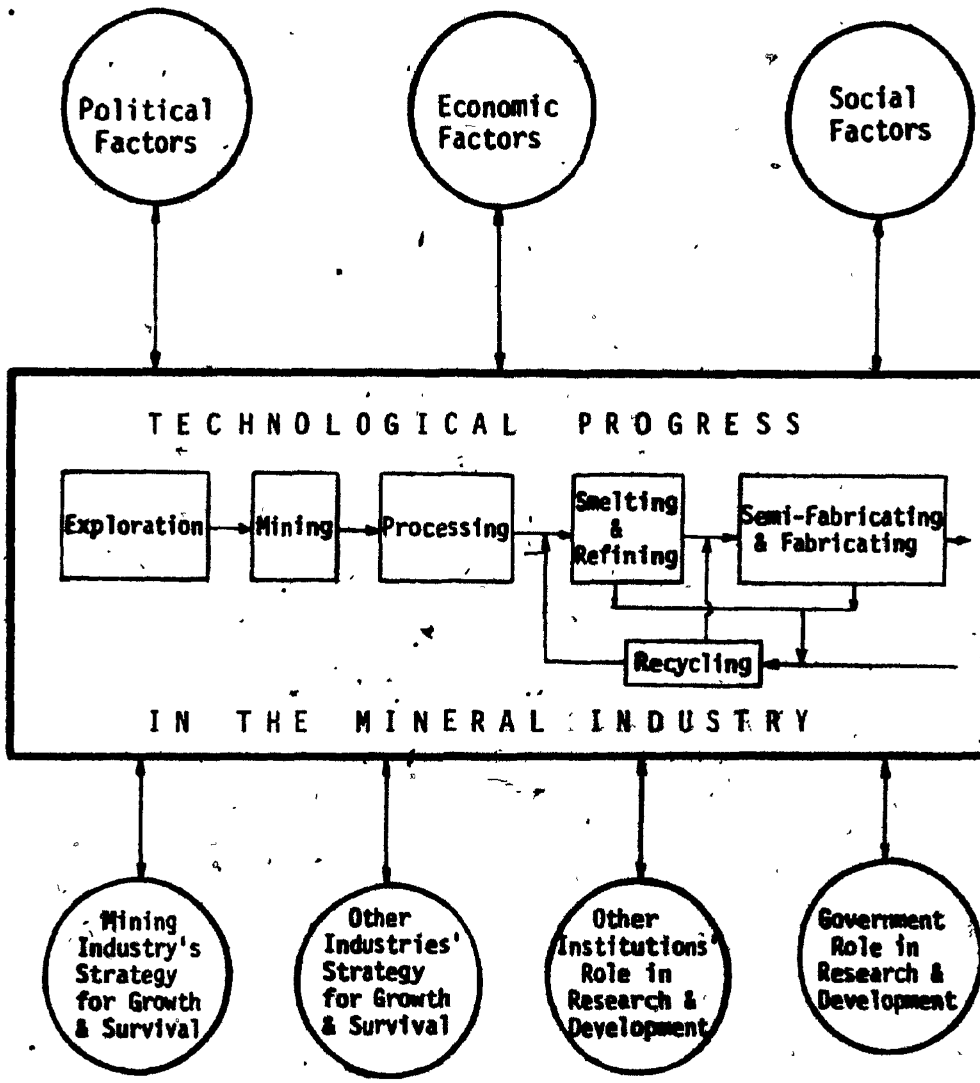
[1] The analysis is limited to those factors that influence the innovation process in the ferrous and non-ferrous sectors. Any further reference to the mineral industry refers to these sectors.

Figure 2: FACTORS AFFECTING THE INNOVATION PROCESS IN THE MINERAL INDUSTRY



social). However, because these factors are not independent, there is a mutual interaction among them and with the innovative process itself.

An exhaustive analysis of the factors affecting the innovation process is beyond the scope of this study. Thus, only a brief review of their main characteristics is undertaken in order to contribute to the technology assessment of mineral R&D activities. Emphasis is given, however, to those areas of relevance for the development of an assessment framework for the mineral-based research activities.

2.2.1 Political Factors

The evolution of political forces has had a decisive influence on the development of the mineral industry and on the introduction of new technologies. The development of the capitalist system initiated by the Industrial Revolution in the 18th Century, the emergence of a large number of "Third World" countries in the last few decades, and the development of a number of centrally planned economies after the Second World War need to be considered among the political factors that form the frame of reference for technological progress in the mineral industry. Thus, for example, the structural changes in the mineral industry that have recently taken place on the world scene are a consequence of the evolution of these political forces.[1] These structural changes have reduced the mineral producer's confidence that the Third World countries' mineral resources will meet future requirements. These changes subsequently have driven them to look for minerals in countries with more accommodating political climates. Improved technologies have been developed, therefore, to face less favourable geological, geographical and climatic conditions.

This trend has been reinforced by the possibility of mineral shortages and consequently higher prices for mineral products resulting from

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1 The nationalizations carried out by developing countries have profoundly modified the structure of the world mineral industry.

decisions made by groups of mineral producer countries linked in cartel-type associations. For example, the formation of the International Bauxite Association (IBA) in 1974, coupled with the Bauxite Production Levy Act passed by the government of Jamaica and moves by other bauxite-producing countries to increase revenues from bauxite production gave rise to apprehension regarding the availability and price of bauxite and alumina at a time when aluminum metal was in short supply. Thus, an intensive research and development effort was undertaken by aluminum producers to develop non-conventional aluminum resources: clays, shales, anorthosite, alunite, fly-ash. Alcan, in partnership with Pechiney/Ugine-Kuhlmann, has successfully developed an experimental process for treating aluminum-bearing clays. The U.S. Bureau of Mines has been sponsoring some pilot plant projects of its own.

2.2.2 Economic Factors

2.2.2.1 The Demand for Mineral Products

The R&D process in the mineral industry has been greatly influenced over time by the pattern of world mineral consumption, which, in turn, has been largely a function of the stage of economic development in the various countries and regions of the world, together with the rate of economic growth. Therefore, it is not surprising that the industrialized countries have consumed the major share of the world's minerals.

Consumption of mineral raw materials on a large scale started with the Industrial Revolution and has continued to grow at an extraordinary rate. Thus, for example, copper manufacturing was changed from an industry which had previously been mainly concerned with producing buttons and pins and providing the basic material for sculpture and other fine arts, to one which supplied an entirely new market for heavier industrial goods. Consequently an entirely new technology arose from this need (Prain, 1975).

The development and growth of the new automobile and electrical industries created a great demand for iron and steel as well as other mineral-based products. For example, the automobile industry, which in 1900 was insignificant as far as mineral demand was concerned, is now one of the biggest consumers of metals. An outstanding development in steel during the 1920s - continuous wide strip rolling - is considered as having been induced by the great demand for steel (Gale, 1967).

2.2.2.2 Mineral Production in the Economy and the Level of Research and Developmental Effort

Mineral production in the first post-war decade grew faster than manufacturing production. However, the rate of growth slowed down during the 1958-1970 period and the production of the mineral industry became less important than the output of other sectors of the economy in most countries of the world, with the exception of Latin American nations where the exploitation of iron and bauxite deposits experienced a rapid expansion. Thus, the growth rate of mineral products is appreciably below those of production in general. As a result, their share in production and in capital formation has declined. For example, the share of the United States mineral industry in industrial production in relation to GNP dropped from 3.9% in 1950 to 2.3% in 1970. This has not been the case in Canada, however, where mineral production as a percentage of GNP has grown from 5.8% in 1950 to 6.8% in 1970 (Richardson et al, 1976).

In general, the relative importance in the economy has shifted to the industries with higher knowledge content and these are also the most dynamic, e.g. nuclear, aerospace, electronic and chemical. This trend has made larger investment in industrial R&D necessary in order to maintain the growth rate of these sectors. This is contrary to what happens in the mineral industry as a whole. The decline of its share in production and in capital formation reduces the interest of firms in mineral R&D investment and the ratio of R&D expenditures/value of mineral production has declined progressively. In the case of Canada, mineral industry expenditures on R&D have diminished in absolute value in the last few years, reflecting the effect of the economic cycles. Table 1 shows the mineral industry expenditures on R&D in Canada.

Table 1: MINERAL INDUSTRY EXPENDITURES ON R&D* IN CANADA
(Millions of Dollars)

	MINES (Excl. Oil & Gas)		METALS**		MINES & METALS
	Current $	1971 $	Current $	1971 $	1971 $
1971	14.7	14.7	59.7	59.7	74.4
1972	12.2	11.6	62.2	59.2	70.8
1973	15.5	13.5	61.8	53.9	67.4
1974	15.0	11.4	74.7	56.7	68.1
1975	18.6	12.7	91.3	62.3	75.0
1976	16.1	10.0	99.1	61.8	71.8
1977	17.3	10.0	99.5	57.8	67.8

* Composed of expenditures funded by performers and excludes government assistance to industry. Figures include current and capital expenditure and extramural R&D funded by the industry.

** The term "metals" comprehends primary ferrous and non-ferrous processing activity and metal fabricating.

SOURCE: The Science Statistics Bulleting (Cat. No. 13-003)

2.2.2.3 Mineral Resources, Price and Technology

Historically, technologies employed by the mineral industry have needed to adapt to an increasing demand. In order to meet this requirement, new equipment and techniques with greater capacity and higher productivity have been designed. On the other hand, these new technologies were developed to face the progressive decline of ore grade for some types of mineral deposits (e.g. porphyry copper) and the exhaustion of certain types of mineral deposits and their replacement by others with lower grades and/or more complex processing and refining (e.g. porphyry copper deposits at the turn of the last century, taconite iron deposits some decades ago and lateritic nickel deposits in recent years).

The amount and form in which minerals occur in the earth ultimately control trends in production.[1] Three fundamental geological factors that affect long-term availability of mineral resources are usually mentioned: the amount of metal available in the earth's crust in each range of grades; its mineralogical form and chemical state; and its spatial distribution. Although their effects vary from metal to metal, the factors apply to all. Thus, some time in the future, it will probably be necessary to rely on silicate minerals for some metals now produced from non-silicate minerals.

Mineral technologies for finding and producing mineral materials in most cases have outstripped demand for minerals, resulting in progressively lower real prices for minerals. Price reductions have been accompanied not only by increased consumption but also by steadily increasing reserves (Nordhaus, 1974).

Among the major technological achievements that have contributed to increase mineral supply and to the economic justification of producing from lower grades of ore have been the flotation process, the process for making pellets from taconite iron ores, and the ammonium pressure leach process for extracting nickel from lateritic ores.[2]

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1 A great many variables will affect the future production of metals. Social, economic and technological changes have greatly influenced and will undoubtedly continue to influence metal production. Important as these variables are, they cannot be used alone to determine long-term availability of metals (Singer, 1977).

2 Sherritt Gordon, a Canadian company, has done much of the pioneering research in the processing of lateritic ores.

2.2.2.4 Economic Cycles, the Investment Process and Technological Change

An important characteristic of mineral supply and demand responsible for cyclical fluctuations is the substantial impact that changes in the overall level of economic activity have on the demand for most mineral products. As a result, for most mineral products the demand curve shifts considerably over the economic cycle. The heavy use of mineral products in industries of capital and durable goods where production is greatly affected by changes in the overall level of economic activity (appliance and equipment; automobile and other transportation; construction; electrical and machinery) is largely responsible for the cyclical fluctuations affecting the mineral industry (Tilton, 1977).

Economic cycles in the western industrialized countries are becoming increasingly synchronized as their economies have grown more integrated and interdependent, and consequently the mineral industry is becoming more vulnerable to cyclical fluctuations; hence the instability of mineral markets has increased in severity (Tilton, 1977; Menshikov, 1975). The last recession for steel provides a clear example. The demand for steel in the United States was increasing at less than 3% per year during 1978; thus expansion of any kind was a debatable proposition (Faltermayer, 1978). Steel consumption in European countries was not better either. This was not the case for Canada, where the average age of steelmaking plants is estimated to be about 10 years and domestic consumption during the past 20 years has expanded at an annual rate of 5.5% (Anderson, 1978).

The development of techniques and technology proceeds irregularly, in the form of specific techno-economic cycles. Each of these cycles opens with revoluntionary changes in production techniques, followed by a period of evolutionary assimilation and improvement of the new technology. Then another breakthrough takes place.

The emphasis shifts from one form of R&D to another according to an evolutionary or revolutionary period. The period before a revolutionary breakthrough demands high-level basic research and inventive activity. The evolutionary period (with a total increase in the volume of basic research and inventive activity) involves a relatively faster increase in development work.

Revolutionary changes in technology lead to changes in economic relations; through the mechanism of market competition they greatly influence the economic cycles of industrial development. The massive replacement of existing equipment, prepared objectively by a revolution in technology, becomes an economic necessity under the impact of cyclic economic development and creates a powerful stimulus to R&D. It is evident that the shorter the interval between the revolutions in techniques, the greater the demand for the renewal of fixed capital invested in production, as well as for the advancement of R&D (Nikolayev, 1975).

Economic cycles invariable have contradictory effects on technological progress. Initially these check or slow down development because the market shrinks; then depreciation of capital occurs, a fall in the rate of profit forces firms to seek new technical and economic solutions to expand the market, cut production costs and thus increase their profits.

The replacement of obsolete capital goods by new investment and the building of new enterprises proceeds unevenly. Every new economic crisis, by forcibly restoring the equilibrium previously upset, opens up possibilities for a new round of extensive capital investment. This occurs only when the rate of profit, after the last crisis, returns to an attractive level for the firm. In the past, however, not every type of equipment was replaced immediately after each crisis. This replacement process could develop, subject to the availability of financial resources of entrepreneurs (Menshikov, 1975).

A case in point is the United States steel industry. Part of its current troubles stem from imports which have reduced profits, causing investment to be postponed and eventually cancelled. The major problem, however, is that many plans are worn out and obsolete. The industry has been extensively modernized since 1960 and capital expenditures over the last 10 years totalled $21 billion. Despite this level of spending, there still remains a significant need for additional modernization of plant and equipment.

Research and development expenditures represent capital investment of a special type. In contrast to ordinary investment which goes for the purchase of equipment or buildings, resources are spent on information-gathering for the creation and improvement of a product or process technology and not for the buying of plant.

In the eventuality of success, R&D investment can bring a high level of profit and a swift recoupment of the expenditure. Owing to its special profitability, R&D investment is less subject to cyclical fluctuations than is ordinary investment. If financial possibilities allow, firms utilize a period of comparatively low economic activity for experimental work with new equipment and new products (Menshikov, 1975). For example, during the 1914-18 war, the demand for nickel was high. After the war demand decreased and a recession period followed. The Canadian producer, INCO, in weaning itself from the war economy, undertook a program of research and market development designed to diversify sales. This strategy met with considerable success as the growing automobile and radio industries provided substantial new outlets for the various nickel alloys (Deverell, 1975).

During boom periods, the swift rise of demand makes it possible to sell existing types of goods profitably and to work with the ordinary types of equipment available on the market. During these periods it is unprofitable to experiment with new goods. Moreover, there are shortages of free capacity in such times.

The countercyclical movement of investment in research has its limits. If the crisis is sufficiently acute and prolonged it may prove to be disadvantageous to put the results of research into production.

There are considerable disincentives in the mineral industry to use new technology and replacement investment is relatively hard to justify because of high risk, including short uncertain mine life. The increasing capital costs and decreasing incentives of new mining ventures progressively tend to make the industry more conservative in its desire to avoid risks additional to those inherent in the uncertain nature of ore-bodies and the flutuating hazards of markets. This creates a serious hold-up in the flow of innovations into industrial practice. Inventors, universities and other research organizations can usually show that their new processes work under favourable conditions, often on a small and discontinuous scale. Laboratory conditions are either of the small batch type or closed-circuit recycling to avoid having to cope with large quantities of ore; therefore they cannot fairly reflect the conditions of industrial through-put. Consequently, information provided in this way on product grade, power consumption and long-term continuous running reliability is clearly insufficient. At this stage there is thus a serious credibility gap which many inventions fail to bridge; even the successful ones may take up to twenty years to atain full industrial acceptance. Some five or six years of this time may be spent in arranging support for the production of an industrial prototype for long-term applications testing on production lines at mines (Cohen, 1976).

The present cost of properly designing and building a prototype unit, with attendant requirements for patenting, pre-prototype test, etc., is very high and is rapidly increasing. The development of a new technology for ocean mining illustrates this trend.

2.2.2.5 Substitution in the Materials Market

The preference for one material over another is determined by the interplay of technology and price. The user will not change to another material on the basis of price alone. Consideration is also given to the overall technical problems associated with the substitution.

During this century, potential substitutions for mineral based products and the availability of mineral resources have played a significant role in increasing mineral producers' efforts to capture a share of the market for the "new metals" (aluminum, nickel, magnesium, titanium) in place of the traditionally employed "old metals" (copper, lead, zinc, tin and, more recently, steel). This has been a great stimulus to the undertaking of systematic R&D programs to develop new processes and products, to improve existing processes or to up-grade the characteristics of existing materials.

2.2.3 Social Factors

2.2.3.1 The Labour Force

The decades following the Second World War have been marked by a high level of industrial development, giving rise, in turn, to some new labour trends as well as reinforcing others which already existed. Some of these labour trends extend to all industrial sectors and have a broad influence over technological progress although this influence varies with the particular industry in question.

Among these labour factors are: a higher level of education and better technical skills attained by the labour force; the growing attraction of the labour force to urban centres; a greater number of trade union members and trade unions; and the increasing influence of the labour unions. Other factors more specific to the development of the Canadian mining industry are associated with the establishment of mining communities in remote and isolated areas and the high labour turnover rate which characterizes the labour force in the mining industry.

All these factors work together to stimulate R&D programs aimed at improving health and safety conditions in the work place and to mechanize and automate the most hazardous operations. For example, these have been major considerations in the development of the raise-and-tunnel borers for hard-rock mining.[1]

The replacement of manpower, first by machines for energy sources and, more recently, by a great variety of instruments and automatic controls to provide continuous attention, has been a dominant motive of this century. The hard fact is that the cost of labour has always increased at a greater relative rate than the cost of either power or supplies. Thus labour has been the principal target for cost reduction.

2.2.3.2 The Conservation and Environmental Movements

In the last fifteen years, new social trends have emerged in developed countries to produce changes in the mineral industry and stimulate R&D related to these changes. These trends are the conservation and environmental movements.

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[1] The introduction of these machines has spurred technological improvements in the conventional raise-and-tunnel equipment and techniques, which have been greatly reduced in cost. They can compete advantageously with the tunnel and raise borer, thus retarding full adoption of the new technology.

The importance of the conservation movement in this context is that it has created a polemic that has helped define the problems now facing the mineral industry. These problems will undoubtedly increase in the future but an initial consequence has been to emphasize the importance of mineral materials hitherto unexploited and to create incentives for the development of technology required for their exploitation.

With regard to the extraction of mineral materials, the environmentalists' position has exerted considerable influence in the development of a number of innovations designed to reduce the possibility of irreversible damage to the environment or to reclaim damaged sites. For example, new mining methods have been conceived to minimize the subsidence resulting from underground mining and reclamation research has been carried out on re-vegetation and rehabilitation of mine sites.

There is mounting pressure from groups which consider their well-being threatened by pollution to find solutions to these problems. A number of technologies have been developed to deal with pollution resulting from mineral processes. For example, R&D seeking a long-term solution to pollution problems has focussed on the development of hydrometallurgical processes which do not produce sulphur oxides - a major source of pollution. Hence, Sherritt Gordon Mines have developed a high temperature and pressure process for beneficiation of nickel-cobalt sulphides, and a chlorination process for beneficiation of zinc, lead, copper complex ores is currently under development at the Canada Centre for Mineral and Energy Technology (CANMET).

2.2.4 The Mining Company and Research and Development

2.2.4.1 Mineral Producers

R&D is an important component in strategies for growth and survival in the mineral industry but its importance varies according to the size of the mining company.

The small operator has limited ore reserves and other resources and faces long-term amortization of equipment and installations. In addition, the small operator's future is uncertain because of the fluctuation of mineral prices in the market. Thus his major concern in ensuring his survival is exploration for new reserves and, in order to avoid further risk, he is reluctant to innovate or to adopt new technology.

In general, the small mining company, given its low rate of production, does not normally have any incentive to carry out formal R&D programs. However, it may invest in such activities if faced with technical or economic problems that threaten its existence, requiring an improvement in operational efficiency.

Similarly, the independent semi-fabricator or fabricator with a small production does not carry out systematic R&D programs as there is limited incentive to do so. Through R&D he could reduce his operating costs but would hardly increase his sales which are dependent on final consumption.

In contrast, output from the largest mineral producers accounts for the major share of production and any decision made by them has considerable impact on the whole industry. Usually, the largest producers integrate their operations vertically, the degree of this integration varying according to the mineral product under consideration. In spite of the diversity of alternative strategies followed by the largest mineral producers and the complex picture that emerges from this situation, it is possible to find common elements in relation to R&D.

(1) The largest producers are in the best position to conduct long-range R&D programs since they are in possession of mineral reserves which allow production over a reasonably

long period of time. Furthermore they have rich and varied industrial experience and the required financial resources, or access to these.

(2) Large mining companies integrate development activities and by doing so are able to patent and license new processes. They perceive that possession of proprietary rights to a process that reduces the costs of mineral recovery allows them to make greater profits than their competitors. Thus they may carry out R&D activities to recover minerals at lower cost or to develop new techniques to process ore from deposits which they have discovered but which cannot be economically exploited under present conditions.

(3) Large mining companies show a more flexible attitude toward the modernization of equipment and the improvement of existing processes as well as the adoption of new techniques. In addition, they co-operate more closely with equipment manufacturers and processers in order to implement innovations.

On the other hand, the innovation process for base metal products has been somewhat inhibited by the discontinuity which exists between producers of metal products and the semi-fabricators and fabricators. Thus, metal producers see few incentives to conduct R&D for new products and new uses since this is not perceived as part of their business. Only recently, in order to face strong competition from other metals and materials, primary producers have initiated a defensive R&D strategy designed to avoid further market losses.

2.2.4.2 <u>Equipment and Process Suppliers: Competition and Innovation</u>

Another major factor bearing on technological progress in the mineral industry is the competitive pressure to innovate which is found in the mining equipment and material supplies market. Equipment and material suppliers, in an effort to increase their share of the market or to avoid a loss of it, have been important sources of innovation over time.

The development of new mining techniques is performed primarily by machinery and electrical equipment companies, whereas research on minerals is carried out by the chemical and oil-refining industries. This is due mainly to the higher rate of technological progress accruing to these industries, the need to find new market outlets for their products, and the structure of the mineral industry. Mining equipment suppliers profit from innovation, both through a larger share of the equipment market and an expansion of the total sales of equipment that accompanies an accelerated rate of obsolescence of existing machinery and the increased consumption of mineral products.

In relation to the Canadian suppliers for the mining industry, Richardson et al. (1976) state that the supply industry in Canada has certain characteristics which seem to inhibit domestic R&D activities. They argue that, since most of the large companies are owned by foreign corporations and act as subsidiaries in the Canadian market, these tend to be oriented primarily towards that market. Consequently, these companies have little or no applied R&D capability in Canada (the parent organization usually having a research centre in its home country), and frequently the manufacturing operation in Canada is little more than an assembly and service operation. It is also contended that it seems unlikely that small suppliers have the resources necessary to effect a continuing program of process innovation for the mining industry. Under these circumstances it is not surprising that, in spite of the fact that the Canadian mining equipment market is currently the second largest and considered to be the most technologically advanced in the world, only 26 percent of the total drilling, mining and concentrating equipment sold in Canada in 1974 was manufactured by companies incorporated in Canada (Findlay et al., 1977). On the other hand, and in sharp contrast, some of the largest equipment suppliers in Canada are among the most innovative. Companies like Joy Manufacturing, Jarvis Clark and Gardner Denver are often mentioned in this respect.

2.2.5 Technological Progress in other Industries

The accelerated advance of science and technology, particularly in the last few decades, has created the basis for the development of new industries requiring new materials and of new sources of abundant, cheaper energy. For example, the growth of mechanization and the increased reliance on capital equipment has been supported by increased availability of energy and power based on natural fuels and hydro-electric sources. This was possible only because of technological developments that took place in these industries. The development of nuclear energy technology, which created a demand for the exploitation of uranium deposits, is another example. As by-products, the exploitation of uranium deposits made available a number of mineral products associated with uranium ores.

The search for ways of reducing energy consumption has resulted in continuous improvement of mineral product processes. Recent increases in energy prices have stimulated greater research efforts to reduce their impact on production costs of energy-intensive mineral products (e.g. aluminum, magnesium, titanium).

The recent development of some knowledge-intensive industries, such as aero-space, computers, telecommunications, has created a demand for high performance mineral products (e.g. titanium alloys, semi-conductors). Although the impact of such industries is significant in dollar value terms, it has been less dramatic than the impact provoked by the energy industry.

2.2.6 The Role of Non-Profit Institutions in Research and Development

The major impact of universities in the innovation process for the mineral industry has been indirect, mainly through basic research contributing enormously to the advancement of knowledge in all disciplines and through the education of the engineers and scientists who perform R&D. Non-profit research institutions, although undertaking research more closely related to short-term industrial needs, have played a secondary role in mineral R&D because of their limited efforts.

2.2.7 Fiscal Policies and Technological Progress

Following the Second World War, the governments of industrialized countries have increased their control over the economy and R&D has been one of their major concerns. Direct government intervention in industrial R&D has been translated into large R&D expenditures. On the other hand, governments are in a unique position to have great influence, by means of various fiscal policies, on the R&D carried out by the private sector.

(1) From the point of view of stimulus to technological progress and the process of capital renewal in the mineral industry, the fast write-off of capital costs for tax purposes encourages investment in the replacement of equipment and the introduction of new technologies with higher productivity.

(2) Protectionist fiscal policies, such as tariffs, quotas and procurement, designed to protect domestic mineral industries and to limit competition from abroad, slow down the rate of investment in R&D and retard the adoption of new techniques. Consequently, and contrary to what is being sought, the long-term effect of these policies is to expose the protected industry to even higher future risks.

(3) Foreign trade policies can stimulate the development of a technological capability in the exporting country. International credit, aid as well as trade agreements, helps to find markets for the export of domestically produced technologies.

The impact of all these factors in the Canadian context is analysed briefly in the next section which deals with the development of industrial R&D in Canada.

2.3 Industrial Research and Development in Canada

Industrial R&D and its impact on the economy have received growing attention in Canada during the last few years. A number of studies related to these matters have been undertaken and reports have subsequently been published by governmental and parliamentary commissions as well as by private and semi-private institutions. The subjects of these studies range from the history of the most important research centres to the formulation of a comprehensive and coherent Canadian science policy, its discussion and the analysis of its preliminary results. This interest is due, obviously, to the recognized and increasing importance that industrial R&D plays in the continuous progress of contemporary Canadian society. Because of this fact, the Canadian government has tended to stimulate R&D in Canadian industries through diverse initiatives.

The present situation of scientific and technological research in Canada and, in particular, the progress of industrial R&D in the mineral industries cannot be fully understood without considering their past and their evolution. Consequently a brief review of the accomplishment, deficiencies and perspectives of Canadian R&D is presented in this section.

Canadians are backed by more natural resource wealth per capita than the citizens of any other land. It is not surprising that some of the first scientific interest in Canada was focussed on these resources. The intervention of the Canadian government in the matter of research was oriented towards exploring and developing an extremely vast territory and then to assess the potential and exploit the ample and abundant resources of the subsoil. It was for these purposes that the Geological Survey of Canada was created in 1841. The founding of the Geological Survey and the publication in 1863 of the "Geology of Canada" laid the foundation for the Canadian mining industry. The industry did not become prominent until the 1890's in British Columbia, and the early years of this century when rich deposits of gold and silver were discovered in northern Ontario. The Canada Centre for Mineral and Energy Technology (CANMET), the present-day descendant of the Mines Branch which was created in 1907, together with the Geological Survey, were the origin of the present Department of Energy, Mines and Resources (EMR).

The very important place of agriculture in the Canadian economy and the exploitation of mineral resources explain why research in these areas is still a major element in the government industrial research sector in Canada. In 1974 their total R&D expenditure represented about 14% of total R&D expenditure of the federal government and their in-house R&D expenditure about 26% of the federal government's total intramural R&D expenditure. The bulk of the research financed by these bodies is carried out in their own laboratories. In 1974, the intramural R&D expenditure of the Department of Agriculture represented 99 percent of its total R&D expenditure, while the percentage for the Department of Energy, Mines and Resources was 89%. (Cordell and Gilmour, 1976).

The Mines Branch has, since its creation, played a preponderant role in mineral R&D. For example, during the thirties the Mines Branch laboratories were considered to be some of the main federal government laboratories involved in research (Lamontagne, 1972). At that time the Mines Branch laboratories were regarded as being concerned with the character of the mineral resources located by the Geological Survey. Its Divisions of Ore Dressing and Metallurgy, Fuels, etc., were generally recognized as being concerned with the utilization of mineral resources; the Ore Dressing and Metallurgical Division focussed more particularly on the winning of metals from ores. Some coordination of effort between the Mines Branch and the more recently created National Research Council (NRC)[1] was also sought at that time in order to avoid duplication in mineral R&D.

From 1945 to 1960, new organizations related to science and technology were established and new major R&D programs were initiated. For example, in 1944 Eldorado Mining and Refining Ltd. was founded as a Crown company for the task of mining and refining uranium ore and for the production of nuclear fuels. Atomic Energy of Canada Limited was created in 1952 to carry on the Canadian R&D nuclear program. The federal government's decision was to continue and enlarge the major program in nuclear power.

During the sixties, several specific subsidy programs of aid to industrial R&D were started. The programs that related to mineral R&D were the Industrial Research Assistance Program (IRAP), administered by NRC, and the Program for the Advancement of Industrial Technology (PAIT), administered by the Department of Industry, Trade and Commerce (IT&C).

In 1973 only one federal government department (Energy, Mines and Resources), out of eight which participated in conducting mineral research, has the development of the mineral industry as a specific mission. EMR's expenditures in research for that same year represented 46% of a total of $24.9 million spent by all government institutions in mineral R&D. More than half was spent in support of programs in seven other departments or agencies, mainly Industry, Trade and Commerce (PAIT) - 16.5%; National Research Council (IRAP) - 16.5%; and Atomic Energy of Canada Ltd. - 16.4%. The remaining 3.4% was spent on programs of the Departments of Environment, Health and Welfare, Regional Economic Expansion, and National Defence (CANMET, 1974). The fact that

[1] The NRC was created in 1917 but the construction of laboratories on a large enough scale to conduct industrial research began in 1930; by 1935 these laboratories were in operation.

agencies other than EMR contributed so heavily to mineral R&D was found to be partly fortuitous and partly due to the initiative of industry and university R&D staffs, and only slightly, if at all, due to coordinated government planning aimed at specific goals related to the mineral industry.

In 1972, and as a consequence of the severe criticisms for the lack of a coherent industrial research strategy, particularly by the Lamontagne Report (1972), the federal government announced the "Make or Buy" policy directed at making a new and more comprehensive effort to strengthen industrial R&D. Thus, the government announced its intention to move an increasing part of publicly financed R&D from government laboratories to industry.

Under this policy, the federal departments should normally contract out new or additional research for which capability exists or can be developed in industry. New research done in government facilities should be justified by criteria such as consideration of national security, lack of suitable industrial capability, and research activities essential to provide direct support to a regulatory function. Lately, this policy has been expanded to allow financing of unsolicited proposals for R&D from the private sector.

Industry reacted favourably to this policy, though with some reservations. Recently some preliminary results concerning this new policy have been published (Ministry of State, Science and Technology, 1976). It seems, however, that government efforts were still considered insufficient by some industry representatives.

As a response to the Canadian industry requirement for incentives for firms to undertake the risks of in-house R&D and to untie gradually their dependence on imported technology, the federal government announced in 1977 the new "Enterprise Development Program" (the sole successor to the proliferation of research subsidy programs). Its statement of purpose is "to enhance the growth of the manufacturing and processing sectors of the Canadian economy by providing assistance to selected firms to make them more viable and internationally competitive" (Crookell, 1977).

Another effort that has recently been initiated is aimed at commercializing successful innovations in government laboratories. The Pilot Industry/Laboratory Program (PILP) provides funds to enable the transfer of technology from government laboratories to industry and its subsequent scale-up, which is usually the most expensive part of commercializing R&D.

These programs have been considered by Canadian industry representatives as important steps in the right direction. They consider that building technological expertise requires strong economic rewards for success, not protection from the risk of failure and certainly not extensive red tape legalism.

In summarizing this section, it is possible to conclude that, over the years, much has been written about what government laboratories should be doing and how well they should be performing in one area or another. However, this is not based on the historical conditions within which each laboratory was established; rather, it appears that those who assert that laboratories should be doing more or less of any activity have a highly simplified model of the government scientific establishment that does not correspond to reality (Cordell and Gilmour, 1976).

In general, government expenditures are justified whenever they provide a public good. Public goods are usually commodities or services that everyone wants but the private sector is not willing to supply since it cannot obtain a profit from them.

In Canada, for example, where industry comprises both foreign-owned and Canadian-owned companies, industrial R&D has been carried on at a very low level. In the foreign-owned companies, the concern for

Canada's technological future has been minimal, while Canadian companies either have been engaged in low-technology activities or have not carried out any R&D.

Because of extensive penetration by multinational corporations, Canada receives much of its technology in fully embodied form from the parent to the subsidiary. Transferring technology from a foreign source in this fully developed and detailed form will have the effect of favouring foreign suppliers of materials and parts. This is the reverse of what happens when technology is developed and elaborated domestically (Richardson et al., 1976).

It is in this context that government expenditures for scientific activities in a wide range of areas become necessary to cover the insufficiency of the private sector. Thus, the expanded role of government in social welfare, maintenance of the economy, international matters and elsewhere has spilled over into areas of scientific activity.

The federal government has been involved in a variety of scientific activities for over one hundred years. Recognition of the growing need for industrial research coincided with the First World War. Since then, government-funded R&D has been undertaken in government establishments rather than in private ones because, it was concluded, the only satisfactory way of establishing an industrial R&D capability was first to establish an in-house government capability.

However, the opposite functions, goals, approaches, values and end results that typify science and industry have been the source of conflicts between them. For example, one of the major comments made by mining firms on Canadian government research agencies is the lack of ability within the agencies to develop a usable process. Two problems have been mentioned in this respect. The first was the slow rate of diffusion for new technology developed by the government. The second was the orientation of government work to basic research versus applied research or development.

New government initiatives like the "Make-or-Buy" policy have stemmed from the recognition of these differences. The aim of this policy has been to increase the proportion of government-funded R&D carried out under contract by industry as opposed to government laboratories.

CANMET (initially known as the Mines Branch) has, since its creation in 1907, been the main government agency in charge of conducting mineral R&D necessary for the development of the Canadian mineral industry. However, due to the lack of a coherent and comprehensive mineral policy, government efforts in mineral R&D have been uncoordinated and have responded to partial approaches. For example, government subsidy programs for research conducted by the private sector were used to stimulate the equipment and machinery suppliers for the mineral industry. However, these government mechanisms have been revealed as being inadequate to attain their objectives.

On the other hand, the major share of mineral R&D expenditures in Canada in recent times corresponds to that of the private sector. Thus, for example, Canadian federal expenditures in R&D as a percentage of federal plus industry expenditures represented only 26.7% in 1975. The major portion of the private sector mining R&D expenditures in Canada is spent by the largest mining companies.

From a societal point of view, the Canadian mineral industry has adjusted effectively in the past to the technological challenge which it faced. It owes its present position to its ability to provide reliable supplies of minerals at competitive prices. Canada's mining industry will not remain competitive, however, without continued and increasing scientific input and technological innovation. For example, as a result of the trend towards the use of lower-grade ores, there will be a need for extensive R&D to ease the impacts of the more intensive use of energy in mining and milling and to reduce the pollution and environmental disturbance effects associated with the greater quantities of mine waste.

In particular, government intervention in mineral R&D will be essential to develop technologies which will be needed by the domestic mineral industry in the future but which the private sector has no incentive to undertake.

The critical characteristics of the R&D process in the mineral industry examined in this chapter, in particular the long time-frame required for return on investment, coupled with the high level of uncertainty, emphasize the need to develop improved methods for the evaluation and selection of mineral R&D projects to allow for more accurate planning. The following sections describe the formulation of an assessment framework to optimize investment in mineral R&D. The application of this framework is illustrated with actual case studies. CANMET is selected for the application of this framework because of its long-time commitment and high level of effort in mineral R&D and the broad spectrum of its research activities undertaken.

CHAPTER 3

DECISION-MAKING MODELS FOR THE ALLOCATION OF RESOURCES TO MINING RESEARCH AND DEVELOPMENT PROJECTS

The problem of resource allocation for mineral R&D is complicated by the inherent uncertainty of R&D, the multiple purpose for which it is undertaken, the numerous social and organizational contexts within which it is conducted and the differing values placed upon it by various groups in society. The decision problem of R&D project selection and resource allocation arises whenever the pattern of funding is to be established and when new and on-going projects require more resources than are available. In this way, R&D project selection can be viewed as a specific example of a more general management problem of resource allocation and capital budgeting. In its most common form, the project selection decision is concerned with the allocation of organizational resources, such as money, skills and facilities, to a set of proposals for scientific research and development. The R&D manager must then decide which new proposal should be selected for funding, which existing projects should be continued and what resource levels should be associated with each selected or continuing project.

Project managers consider many criteria when they determine the R&D budget; some are related, others can be treated as constraints, but many must be considered as objectives. Thus the problem is a multi-criterion one. Although decisions on R&D project selection and resource allocation have much in common with other selection and allocation decisions, they are sufficiently distinct to warrant detailed study by numerous researchers. Nevertheless, only a few formal models intended to support mining R&D investment decisions are found in the literature.

There is a wide choice of published methods for the evaluation and selection of R&D projects in other industries, but an exhaustive analysis of alternatives is not proposed in this section. Several reviews of methodology already exist. Instead, a critical analysis is carried out for (1) those models whose characteristics are found to be of interest for the mineral R&D process, and (2) the few published models proposed for the evaluation and selection of mineral R&D projects.

3.1 Literature Survey

Literature reviews by several investigators have revealed the existence to date of well over one hundred prescriptive project evaluation and selection models.

Cetron et al. (1967) in their study selected a number of R&D model performance characteristics which they believed were relevant to one of the United States military services. They proceeded to judge each of thirty models qualitatively to ascertain whether or not it achieved each performance characteristic.

This survey has been up-dated periodically in the prefatory remarks of numerous papers, as is the case of papers by Moore and Baker (1969) and Souder (1972). More recently, the studies of Augood (1973), Clarke (1974) and Baker and Freeland (1975) have reviewed the literature and provided a complete listing of articles and reports which have been published since the study of Cetron et al. in 1967. Table 2 summarizes the content of the relevant portions of the cited papers. It is apparent from these surveys that, to date, no one has come up with an overall system for classifying the various proposed models or techniques. For purposes of the present study, however, the models may be grouped into the following categories.

3.1.1 Ranking and Scoring Models

The cost-effectiveness analysis offers a systematized technique by which the analyst can advise research managers on the order of priority in project selection based on an acceptable criterion.

TABLE 2

SUMMARY OF LITERATURE ON R&D SELECTION MODELS

AUTHORS	MODEL CATEGORIES	COMPARISON AND EVALUATION OF MODELS
Cetron/ Martino/ Roepcke (1967)	Decision Theory Economic Analysis Operations Research	Thirty models are described briefly. These models are compared and contrasted with each other relative to a standard set of features which they may possess. The models are compared in relation to ease of use and to scientific or technological area of applicability.
Moore/Baker (1969)	Scoring Models Economic Models Risk Analysis Constrained Optimization	A brief discussion of each model type is presented. A summary of some accepted descriptive insights is provided. It contains empirical data relating output from different model forms.
Souder (1972)	Scoring Linear Non-linear Zero-one Profitability Index	Scoring model used to assess representative models from each class are discussed. Uses data from 30 actual projects to perform comparative analysis of four models designed to represent main categories.
Augood (1973)	Check Lists Profitability Index Risk Analysis Decision Theory Delphi Technique	A brief description of each model type is presented. A summary of some descriptive insights is provided.
Clarke (1974)	Ranking Models Scoring Models Economic Models Optimization Models	The survey contains a general description of the nature of the innovation decision process. Results of surveys of project selection techniques actually employed are presented. A brief discussion of each model category is provided.
Baker/ Freeland (1975)	Ranking Models Scoring Models Benefit Contribution Models Sensitivity Analysis	A summary of model categories is presented. Areas of applicability are described. Opportunities for additional research are discussed.

Frequently, early stage projects are too hazy for detailed numerical estimation of total research cost, plant capital cost and market specifics. Similarly, basic research could not be expressed in these terms. Since basic research is not directly aimed at the solution of practical problems and the prediction of benefits in an economic sense is very difficult because these benefits cannot be determined in advance, and conflicting goals or objectives and project intangibles may very often not be expressible either in trade-off terms or in the form of limiting constraints, a comparative cost-benefit analysis is not applicable. Nevertheless, a logical set of evaluation criteria can be developed by examining the merits of any research proposal. The use of cost-effectiveness analysis based on scoring models is then suggested for project selection. Consequently, the value of an R&D project, as defined by eq.1 (Chapter 1) is expressed in non-monetary relative terms.

These techniques or models vary tremendously in their degree of complexity. At one extreme there is the simple relative ranking of projects. Examples of this techniques are the approaches developed by Love (1975) and Tauss (1975). Love combines a decision analysis framework with the Delphi method of analysing expert opinion. Thus, this approach formalizes group decision-making by providing channels through which the group members can interact. Tauss' approach is based on pairwise comparison by forced choice to rank and rate R&D projects. First he defines a set of objectives which are rated by assigning number values on a ratio scale by pairwise comparison. Then, for each objective, the existing projects are rated pairwise too. These approaches are far too simple to guide the decisions of large research organizations which involve many R&D projects of different natures.

The scoring models are the next step in complexity. They involve the identification of a small number of criteria or factors which are considered to be critical to the success of a project. These criteria, or factor ratings, can be added or multiplied to produce an overall project score. Examples of this technique of interest to the mineral industry are the approaches developed by Klein (1966), Dean and Roepcke (1969), Benthaus (1970) and Vlad et al. (1972).

Klein's scoring model is based on the rating of three corporate goals - one of which is profitability expressed as expected net present value - and four detrimental factors. The value of a project is obtained by the product of the achievement of these seven parameters raised to the power of the relative objective weight. No reference is made to the experience gained by the application of this model to real cases. Klein's model, intended for research projects conducted by the private sector, is not well suited for the assessment of R&D projects of a more general nature or for decisions made at government research agencies or non-profit research institutes.

Benthaus describes a model designed to assess R&D projects carried on by the coal mining industry of West Germany. In this model, six weighted criteria are multiplied to produce an overall score. In selecting criteria for the evaluation, emphasis is placed on the organizational and technical aspects of the coal mining industry; therefore this model cannot be used for broad application. Benthaus does not discuss the experience obtained through the application of this model.

The model developed by Vlad et al. is another example of a multiplicative scoring model. The value of the product of six weighted criteria is considered for ranking R&D projects of the Romanian mining industry. Three of these criteria are better suited to the evaluation of basic research projects and the other three are intended for the assessment of projects of a more applied research nature. This model is of particular interest to the present study. It represents an attempt to assess mining R&D projects of different research natures and different research stages, characteristic of large research organizations. However, the main weakness of this model is that, in practice, because criteria not applicable are held constant and equal to one, projects of different research natures are evaluated with different sets of critera. As a result, it is not valid to compare model scores when obtained from different types of research. Furthermore, the nature of the budgeting process is ignored, and the experience gained from the application of the model is not discussed.

Preliminary research work conducted by Moore and Baker (1969) suggests that additive scoring models have important advantages over multiplicative scoring models, in terms of a higher degree of rank order consistency. Dean and Roepcke's approach is an example of an additive scoring model. It was conceived for application to military research projects at a large United States agency. This model presents characteristics of interest for the assessment of R&D projects in a large mineral research organization. It makes use of systems analysis; this includes the use of resource costs, the relative value of research projects and information on scientific and technological linkages. This approach takes, as the basic indicator of the value of the output of a project, the extent to which ultimate objectives are satisfied. In this way the difficult problems associated with identifying and measuring intermediate output are avoided. These concepts proposed by Dean and Roepcke are important. In the present study they are used as a basis for the development of a decision-making model for the allocation of resources to mineral research projects for budgeting purposes.

3.1.2 Economic Models

The cost-benefit analysis technique is suitable for applied research activities. These activities are aimed at solving problems of practical value which can be expressed in terms of benefits.

Different models have been developed for the evaluation and selection of this type of R&D project. They differ in their degrees of complexity in estimating the basic parameters, namely, probability of success, net present value given a success, and the cost of conducting the R&D project, as defined by eq.1 (Chapter 1).

(1) Economic models base their investment decisions on a single estimate of criteria such as rate of return, net present value, or benefit-cost ratio. The models of Disman (1962) and Cochran et al. (1971) have been applied to the private sector. This approach has also been applied by Sprague (1969), Robinson (1975) and Fleetwood (1977) to mineral R&D projects.

(2) Constrained optimization models seek to optimize some economic objective functions, subject to specified resource constraints. These models are generally the most complex. They usually employ linear, integer or dynamic programming. Examples of these models are those developed by Hess (1962), Klein (1966) and Allen (1974).

(3) The most recent general class of models is the risk analysis type; these models are based on a simulation analysis of input data in distribution form and provide output distribution of such factors as rate of return, net present value, or market share. Examples of these models were developed by Allen and Johnson (1970), Freeman and Gear (1971) and Maher and Rubenstein (1974). Typically, a risk analysis model utilizes the Monte Carlo simulation technique developed by Hertz (1964) or a combination of this technique with integer programming. Thus, the project portfolio is optimized.

3.1.3 Project Selection Practices

An examination of the relevant literature reveals that very little use is made of formal sophisticated mathematical models in deciding on projects.

Gee (1971), for example, in a survey of project selection practices in the private sector, found it most helpful to classify R&D on the basis of the objective of the work (why it is done) in three categories: Exploratory, High Risk Business Development, and Support of Existing Business. He found that the selection process in Exploratory Research was generally simple and unsophisticated. The project selection in Support of Existing Business was based on standard economic projection since there was a great deal of quantitative data with relatively low uncertainty. The project selection decision in the category of High Risk Business Development was based on a combination of the procedure used in Exploratory and Supporting Research, with some use of more sophisticated and quantitative techniques.

Similarly, Dunn and Harnden (1974) found that 32% of the approximately two hundred Canadian companies studied did not use any project selection techniques. The most popular methods used were simple ranking and economic models. Sophisticated mathematical models were rarely used.

In a review of project evaluation and selection practices at two mineral-based R&D centres, Themelis (1975) indicates that the Noranda Research Centre adopted, in 1967, a simple checklist for the selection of projects. He states that Kennecott Copper Corporation uses no formal procedure for R&D project selection. Major projects at Kennecott, however, are evaluated by a technical appraisal and an economic analysis which includes the use of sensitivity and risk analysis techniques. Themelis stressed that the amount of work expended on technical and economic evaluation of project proposals depends entirely on the stage of development and funds requested.

The lack of use of formal models can be partly ascribed to the facts that (1) most of the models are not able to describe the reality of the R&D evaluation and selection process, its sequential nature and the inter-relationship among projects; (2) the models do not take into account multiple criteria, and risk and uncertainty are dealt with inadequately; (3) the models' lack of sufficient information as input data; and (4) most of the models are considered much too elaborate for the R&D manager's routine use (Clarke, 1974).

Thus, a suitable assessment framework for mineral R&D activities needs to consider the following performance criteria:

(1) Realism - the model must represent the real decision-making process for R&D activities;

(2) Flexibility - the model needs to be used on different types of projects and at different stages of research;

(3) Use - a low degree of difficulty for the R&D manager in using the model should be one of its main characteristics;

(4) Cost - the model must have a low cost of setting up and use.

A formal approach for mineral R&D investment decisions is developed in the next section considering these performance criteria.

3.2 A Decision-Making Approach for Research and Development Project Planning in a Large Mineral Research Organization

In the management of R&D, a large mineral R&D organization with many diverse projects presents particular problems in selecting and timing new projects and in planning the progress of on-going ones. Besides taking into account the merits of individual projects, it is necessary to relate them to the allocation of the available budget, research personnel and research facilities among the different projects. The basic problem, then, is to select projects in a way that will lead to the optimization of the potential pay-off for the whole portfolio of projects, considering the most efficient use of the available resources.

According to the literature surveyed in the course of this study, the cost-benefit analysis technique has a stronger theoretical foundation for resource allocation than the cost-effectiveness analysis technique. However, in practice, the difficulties in obtaining reliable information for the evaluation of a set of research projects at different stages of their innovation process prevent its application to the entire set of projects. Thus, a cost-effectiveness analysis based on scoring models appears suitable for assessing the different research projects and for providing a decision-making tool in matters related to R&D priorities in Canadian mineral-based activities; specifically those concerned with mining, processing and utilization.

Scoring models are neither as restricted nor as powerless as is commonly thought when they are applied to advanced-stage R&D projects. However, their advantage over economic models disappears when economic data need to be processed and the project's associated risk needs to be considered. In dealing with research projects in advanced stages, the most serious shortcoming in the scoring models is the relatively arbitrary fashion in which the models have been constructed. Comparative analyses conducted by Moore and Baker (1969) relating to project ranking produced by scoring models to ranking produced by economic models show that the performance of a scoring model is highly sensitive to decisions made during the development of the model.

Thus, the cost-benefit analysis technique provides a rational framework for decision-making for those projects of an applied research nature requiring a long time commitment and a sizable amount of resources for completion. This approach provides the assessment of the economic and social benefits accruing to Canada from funding of R&D required to develop and introduce technological innovations to the mineral industry.

Consequently, two R&D project evaluation and selection techniques appear suitable for allocating resources to mineral research projects in a large organization:

(1) A cost-effectiveness analysis approach based on additive scoring models. The Delphi method is recommended to attain group consensus among the research centre staff in defining the objectives of the organization and in developing relative weights for these objectives; and

(2) A cost-benefit analysis approach for the evaluation and selection of large R&D projects of applied research natures. It is proposed to use differential economic models according to the research projects' stage. The selected models must be commensurate with the quality and quantity of data available at each project stage.

CANMET - Canada's largest mining research organization - is selected as a specific case study to test and investigate the suitability of these approaches to large mining research organizations. For the purpose of defining the parameters of these approaches, the characteristics of CANMET are examined in the next section. Special attention is given to CANMET's role in planning R&D in the Canadian mineral industry and in conducting research within the Canadian federal government.

CHAPTER 4

APPLICATION OF ECONOMIC PLANNING TO RESEARCH AND DEVELOPMENT PROJECTS OF THE CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY

Canada has developed a strong base for generating scientific input and implementing technological change in its mineral system through government, industry and university. The inter-relationship between these sectors and the innovation process in the mineral industry was discussed in Chapter 1.

The Canadian federal government today plays an important role in mineral research activities. Basic and applied research is conducted by the federal government in most sectors of the mineral industry. Research conducted by the Department of Energy, Mines and Resources (EMR) has as a specific mission to contribute to the development of the Canadian mineral industry.

The largest component of EMR is its Science and Technology Sector. CANMET is an important branch of the Science and Technology Sector; its personnel represented 21% of total EMR staff in 1972, being composed of 658 employees of whom 270 were professionals. The size of the CANMET budget for its mineral R&D activities is significant. In the 1973-74 fiscal year, some $10 million of the CANMET budget was allocated to mining, processing and utilization research projects. (CANMET and Department overheads are not included in this figure).

The importance of CANMET in the historical development of a technological capability in mineral R&D has been stressed in Chapter 1. CANMET conducts fundamental and applied R&D in mining and processing technologies, metal fabrication and work related to environmental impact. An examination of the mineral research activities undertaken from 1961 to 1973 shows that an average of 148 projects per year were carried out and a total of 24 patents were granted in Canada. The number of all kinds of publications amounted to an average of 163 reports per year during the same period.

4.1 CANMET Matrix Management

In response to the general criticisms made in relation to R&D conducted by the federal government and the state of affairs in mining R&D within government research organizations, discussed briefly in Chapter 1, a number of initiatives were made to correct the observed deficiencies. One of these resulted in a new management structure for CANMET.

In 1973 a task force was appointed to report on the effectiveness of CANMET. As a result, a program management method was suggested to replace the traditional functional structure. The introduction of a matrix approach to the management of R&D work undertaken in CANMET was initiated early in 1974.

Matrix management is a system in which the responsibilities for defining, planning, developing and controlling the program undertaken are the functions of program management. The responsibility for the resource aspects (manpower and facilities) by which the program goals are achieved rests with functional management. In CANMET, functional management is comprised of laboratory chiefs, managers and heads of sections. Program management consists of program directors, assistant directors and project leaders. Both program and functional management are responsible to the Director General of CANMET. Under this system, the program directors are responsible for determining priorities and objectives and for issuing the detailed research project structure and related statements, budgets and schedules. The research project structures specify what effort will be accomplished, when it will be performed and which function unit will be accountable.

This new management structure plans and implements research activities through two programs: the Energy Research Program (ERP) and the Mineral Research Program (MRP). The MRP operates across three function units:

the Mining Research Laboratories, the Mineral Science Laboratories and the Physical Metallurgy Research Laboratories.

The MRP has been divided into three component activities - Mining, Processing and Utilization.

Research projects in the Mining Activity are concerned with the mechanical and physical problems associated with efficiently extracting as much of a mineral deposit from the earth as possible and delivering it to a processing plant. Mining technology is not constrained by the particular mineral being mined and thus, broadly speaking, mining may be characterized as a process or operations-oriented industry.

The Processing Activity is concerned with exploiting differences in the chemical and physical properties of minerals to develop processes for producing marketable projects from both metallic and non-metallic ores. Since process technology is a function of the mineral involved, it is commodity-oriented.

The Utilization Activity has two prime concerns. The first is to improve processes by which materials are fabricated and processed into useful products. The second is with developing the optimum properties and performance of product required to solve Canadian material problems. Thus, this project is in part operations-oriented and in part properties-oriented.

4.2 Mineral Research Program Objectives

National goals, as defined in mineral policy documents, are the basic elements that serve to define specific objectives for a government mineral research program. These objectives are, in turn, prerequisites for the development of a decision-making model to determine priorities and to allocate public resources to mineral R&D projects.

The government role in mineral R&D, examined in Chapter 1, shows that this may be exercised through the use of different mechanisms: direct expenditures on in-house research projects, contracting-out research projects to the private sector, and the formulation of fiscal policies designed to stimulate mineral research. Thus, the government can have a significant influence on the innovation process in the mining industry. In particular, government intervention is essential to develop those technologies whose development is not undertaken by the private sector because of lack of incentive and which are essential for the future of the domestic mining industry based on the country's own resources.

In the policy review document, "Towards a Mineral Policy for Canada - Opportunities for Choice" (1974), a high priority is given to the increased diversification and growth of national and regional economies based on minerals.[1] This cannot be achieved without giving due consideration to the technology needed to improve health and safety in the working place and to protect the natural environment. Another high priority item is the assurance of an adequate supply of minerals for Canada's future needs. In meeting these objectives, technological advances that will make it economically possible to mine and process lower-grade, more complex and deeper deposits with increased recovery, and recycle more of the waste will also lead to the extension of the viable life of mines and mining communities, the development of new mining districts, and the conservation of Canadian resources. Thus, technological advances rarely have an impact on a single organizational objective, whether the organization be an industry, a government or a community. This is why the assignment of priorities to R&D activities, even when a clearly stated policy is enunciated, is not an easy task.

Within the context of EMR's Mineral and Energy Resources Program, CANMET's mission has been re-defined as follows:

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[1] A recent government study, "Mineral Science and Technology" (Findlay et al., 1977) considers the role of R&D in the assessment of Canada's future mineral prospects, and the requirements for the development and opportunities for new mining technologies.

"To ensure the effective extraction and utilization of Canada's mineral and energy resources by:

- performing, contracting and co-ordinating research on extraction, up-grading, utilization, conservation and environmental problems;
- providing a technical knowledge base for developing federal government policies and plans;
- providing the public, industry and government with information on advanced technology." (CANMET, 1974).

With such a mission, CANMET tends to be involved in R&D on technological matters and it is concerned to see its findings used in both the private and public sectors. Technology transfer is essential in order to fulfil part of this mission.

CANMET is expected to contribute significantly to the technological improvements that the Canadian mineral sector requires in the future.

CANMET has the responsibility for determining R&D priorities in the minerals and energy areas, for co-ordinating technological efforts of government and private research institutions, for performining and contracting required R&D not being performed elsewhere, and for maintaining an up-to-date knowledge base. There is no implication that CANMET is charged with funding all the work required, either in-house or on contract.

In 1974, a CANMET development team analysed the state of its mineral research activites and their relation to the mineral policy objectives for Canada. It was considered that, although a statement on national goals was available, current and future government strategies for attaining those goals had not been enunciated. However, public statements by Cabinet Ministers had given an indication of government thinking on these matters. Thus, the CANMET development team evolved details of the MRP on the basis of national goals, government initiatives, social pressures and the like.

4.3 A Methodology for Resource Allocation in Canada Centre for Mineral and Energy Technology

The conceptual economic planning approach developed in the previous chapter is applied to the MRP. The aim is to provide a basis for decision-making in matters related to R&D priorities through determination of the relative contributions of various proposed R&D projects to national goals and to the objectives of CANMET and the MRP.

In applying the economic planning approach, special consideration is given to the specific characteristics of the research activities undertaken by CANMET. The following aspects are considered.

(1) According to the role of the government scientific laboratories in industrial R&D and the nature of the innovation process in the mining industry, specially applied research, but basic research as well, needs to be performed in CANMET to accomplish MRP's objectives. Therefore, the contribution of the different research elements to MRP's objectives should be assessed on the same basis.

(2) The rigidity of staff and facilities in CANMET - the problem of transferring government personnel to other activities is a real one, as is that of utilizing or disposing of equipment and laboratory space - imposes constraints on the budget. Consequently it limits the extension of projects and new capital outlays.[1] Thus, only a few research projects reach the development stage.

(3) CANMET's mission contemplates neither the production of industrial prototypes nor the commercial exploitation of the innovations developed by this research agency. On the other hand, reaching agreement with the private sector to carry out

1 Some 82% of intramural expenditures on research by EMR went to salaries in 1972.

development and commercialization of these innovations is, for different reasons, not an easy task. The transfer of technology from the public to the private sector is, therefore, hindered and the economic benefits of an innovation developed at CANMET are difficult to assess.

The cost-effectiveness analysis approach proposed in the previous chapter seems to be suitable to assess the different MRP projects. An additive scoring model, based initially on the technique developed by Dean and Roepcke (1969) and the Delphi method to obtain group consensus among CANMET staff to define the objectives (and their relative importance) relevant for the MRP, is presented. The experience gained over a period of time is analysed in the next section.

The cost-benefit analysis approach is illustrated by its application to two case studies outlined in Chapter 6 - the New Brunswick Complex Base Metal Ores Research Project and the Pit Slope Research Project. These projects involve the allocation of an appreciable amount of public resources over a relatively long period of time.

These applications provide the basis for a discussion of the approach's suitability for a large mining R&D organization and their effect on research projects and people.

CHAPTER 5

THE COST-EFFECTIVENESS ANALYSIS APPROACH

Formal budget analysis and program planning have been under consideration at CANMET since the 1973 re-organization of management. In 1975, the various research management and budgeting systems described in the literature were reviewed by the author with a view towards implementing a suitable system for the Mineral Program at CANMET (Henriquez, 1975).

A decision-making model was subsequently developed by the author for evaluation of the Centre's extensive mineral research activities under the cost-effectiveness criteria. This technique is essentially a scoring model supported by Delphi-type survey procedures. While there may be variations in the Delphi method, its essence is to obtain independent estimates from experts. Each expert is revisited afterwards and shown his response as well as the responses of other experts. He is then allowed to modify his earlier estimates. This cycle of examinations and re-estimation is repeated until a consensus is achieved (Dalkey et al., 1970; Martino, 1970; Love, 1975). The First Scoring Model was implemented in the 1976/77 fiscal year but was too limited to adequately assist management with decisions on fund allocation to the various research projects and to new proposals (Henriquez, 1976). Consequently, a rationalization of various parameters and procedures was undertaken in 1976. The Second Scoring Model represents a departure from the previous one and is somewhat simplified. This model was implemented by the author in the 1977/78 fiscal year (Henriquez, 1977). The concept of marginal cost-effectiveness for assigning priorities amongst competing research projects was incorporated into the Second Scoring Model for the 1978/79 fiscal year (Henriquez, 1978).

A description of the characteristics of the First and Second Models, a discussion of the results obtained and conclusions are summarized in this chapter.

5.1 First Scoring Model

In the search for a suitable methodology to use in allocating funds to R&D laboratory projects in order to accomplish CANMET's long-range time-frame objectives, it appeared that the method developed by Dean and Roepcke (1969) presents certain characteristics that are of interest. Consequently, this model was adapted to the mineral research context and was implemented for the MRP on an experiemental basis for the 1976/77 fiscal year. The main elements and the structure of this model are described in the next section.

5.1.1 Methodology

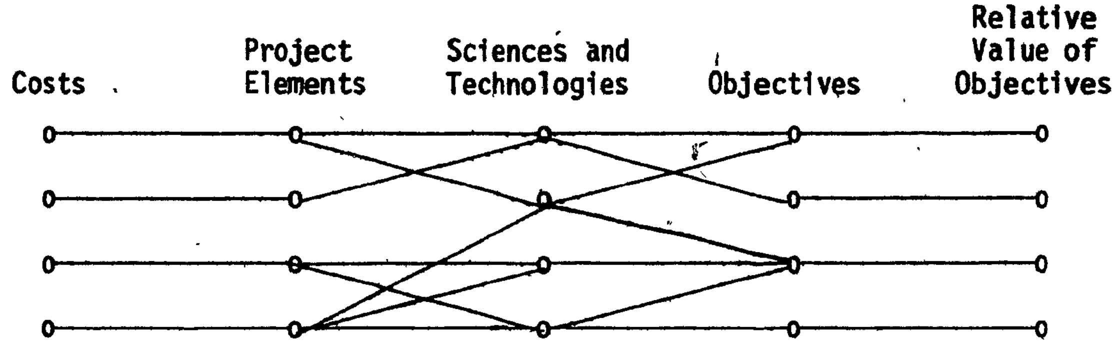
Project activity must, in fact, be related to long-range objectives. This method takes, as the basic indicator of output value of a project, the extent to which ultimate objectives are satisfied. In this way, difficult problems associated with identifying and measuring intermediate output are avoided. Project performance is measured in terms of the contribution of project elements to advancement of science and technology in furthering the achievement of MRP objectives.

The basic elements of the underlying model are:

Objectives of MRP	O_k
Relative values of objectives	W_k
Science and Technologies	S_k
Criticality values of S_j in achieving O_k	b_{ijk}
Project Elements	T_i
Research Project	P_m
Research Activity	A_i
Cost of performing a Project Element	C_i

The element and structure are illustrated in Figure 3.

FIGURE 3: Basic Elements and Structure of the First Scoring Model



5.1.1.1 Value of a Research and Development Project Element

Consider a project element T_i. A number of sciences and technologies may be associated with this project element $T_i \rightarrow \{S_j\}$, where each S_j may be considered to be an output of the project element T_i.

Consider the set of sciences and technologies associated with a given project element $\{S_j\}$. For this project element and set we may estimate the criticality of the contribution of the individual element S_j to the achievement of an objective O_k.

Let

$$a_{ij} = \begin{cases} 1 \text{ if science/technology is required} \\ 0 \text{ otherwise} \end{cases}$$

Then $a_{kj} \times b_{ijk} \times W_k$ is the weighted value of the linkage between the project element T_i and objective O_k, through the underlying science/technology S_j. The sum $\sum_k a_{ij} \times b_{ijk} \times W_k$ measures the value of linkage $T_i \rightarrow \{S_j\}$ expressed over the set of all objectives $\{O_k\}$. Finally, the weighted value of project element T_i may be given by the effectiveness ET_i, where

$$ET_i = \sum_j \sum_k a_{ij} \times b_{ijk} \times W_k$$

An example of the linkage for a mining project is given in Figure 4.

FIGURE 4: Linkage between Project Element, Sciences/Technologies and Objectives

Project Element (T)	Science/ Technology (S)	Objective* (O)	Weight (W)	Criticality (b)
Blasting	Drilling and Blasting	O_1	7.7	0.3
		O_3	7.6	0.5
		O_6	6.5	0.8
	Stability Control of Pit Slopes	O_1	7.7	0.5
		O_3	7.6	0.8
		O_6	6.5	0.8
		O_{12}	4.6	0.2
	Rock Mechanics	O_6	6.5	0.5
		O_9	5.3	0.5
		O_{13}	4.6	0.3

* The objectives relevant for the sciences and technologies considered in this example are defined in Table 3.

Since the project elements are associated with specific activities, the effectiveness of a Project (EP_m) is given by

$$EP_m = \sum_i ET_i$$

and the effectiveness of an Activity (EA_l) is given by

$$EA_l = \sum_m EP_m$$

The effectiveness-cost value E/C, for a project element, a project or an activity is calculated by

$$E/C = \frac{E_x}{C_x}$$

where x represents an element, a project or an activity.

The following assumptions are considered:

(1) The value of achieving several objectives at the same time is given by the sum of values for the individual objectives.

(2) The value of a project element having two critical scientific/technological areas S_1 and S_2 is given by the sum of the individual criticalities. This means that S_1 is independent of S_2 in the sense that the desired accomplishment in S_1 does not greatly depend upon the desired accomplishment in S_2.

When the effectiveness value of the projects has been calculated, it is possible to solve the problem of allocating resources to the different projects in order to optimize their use. A simple model to answer this problem is proposed in the next section.

5.1.1.2 Resource Allocation Model for Project Elements

The resource allocation (or project elements selection) problem is to find the values of y_i corresponding to the project element to be selected, which maximizes the objective function Z.

$$Z = \sum_{i=1}^{n} y_i \times ET_i$$

subject to $\sum_{i=1}^{n} y_i \times C_i \leq CT$ (CT = total available resources),

and $y_i = 1 \text{ or } 0$

This model may be solved using mathematical programming; however, a simple rank-ordering procedure will usually be satisfactory. This method consists of the following steps:

- rank order the project elements on the basis of effectiveness-cost ratio

$$ET_1/C_1 > ET_2/C_2 > \dots\dots\dots\dots > ET_n/C_n$$

- allocate the funds to the first m project elements, such that

$$\sum_{j}^{m} C_j \leq CT$$

The First Scoring Model was applied to investigate the relative merits of the Mineral Research Program projects for the fiscal year 1976/77. The following are the main results and conclusions obtained with this model.

5.1.2 Application of the First Scoring Model

5.1.2.1 Measuring Subjective Estimates

It can be argued as almost inevitable that subjective estimates are biased. The reason behind this preposition is that respondent factors, as well as organizational and environmental factors, cause distortions in the subjective estimates. For example, subjective estimates provided by an expert are, to a great extent, a function of his experience which consists of his knowledge of successful R&D projects which have materialized in the past. Furthermore, scientists tend to over-estimate their own research projects. Finally, a respondent whose field of expertise is not fully coincident or is indirectly related to the scientific area of a project tends to adopt a middle-of-the-road position in his responses. His estimates are usually more optimistic for projects with low probability of success and more pessimistic for projects with high probability of success.

In order to minimize the effect of any individual participant's bias on the overall analysis, great emphasis was placed on having model parameters estimated independently by several different experts. Thus, for each project element, there were multiple responses.

Program and function managers participated in the assessment of models parameters. The major consideration in selecting participants was that they should have several years of prior experience in project supervision. This restriction was imposed in an attempt to minimize biases in measurement. The assistance of the MRP Director was critical in this respect.

It is important to know if subjective estimates rating by R&D personnel are, in fact, accurate and valid indicators of their projects' future potentials. If the project effectiveness value based on subjective estimates is not a valid indicator, then there would seem to be little use in basing prescriptive R&D models on such parameters or in using them at all. Until recently, these considerations have presented a serious impediment to wider application. This impediment appears to be the lack of objective or scientific proof of the validity and reliability of the expert's subjective judgement in practical operations.

There are many reasons for the shortage of convincing evidence. For example, the unique, non-repetitive character of many of the strategic problems to which decision analysis has been applied prevents any controlled comparison. Moreover, only a few organizations have sustained experience in the use of subjective estimates.

However, some studies tend to confirm the reliability of models based on expert opinion. Souder (1969) conducted an experiment to test the validity of subjective judgement in the assessment of R&D projects. He states that subjective estimates can yield valid success/fail predictors for R&D projects under controlled conditions (e.g. when participants are not held accountable to management for their predictions).

Recently, Balthasar et al. (1978) described a successful repetitive application of the subjective judgement of experts to R&D projects at a Swiss pharmaceutical company. To test the reliability of this process, subjective estimates of success probability were compared with the observed frequency of success. It was found that the experts' judgement was fully validated statistically.

An analogous test to verify the model's reliability could be applied to the results of the First Scoring Model. A critical condition in performing this test, however, is the continuous application of the model for a sufficiently long period of time.

5.1.2.2 Mineral Research Program Objectives and Their Relative Values

Given appropriate conditions, one technique employed by decision-makers to resolve multiple opinion is to apply Delphi methods.

A Delphi approach was used to reach group consensus among CANMET management staff (Love, 1975). The application of this approach consisted of defining the objectives relevant for the MRP and developing relative weights for them. A group of mineral policy goals, as defined by the government document "National Mineral Policy Objective for Canada" (1973), was used as a basis for defining the objectives. Because of time constraints, only two Delphi rounds were used.

In the first questionnaire, the panel, composed of 17 participants (CANMET senior management staff, MRP project leaders and some scientists) established relative weights for four major categories previously defined by CANMET senior management staff: (1) social-labour (objectives 1, 8, 14, 15, 18 and 19 in Table 3); (2) ecology (objectives 3, 5, 10 and 12 in Table 3); (3) economic (objectives 2, 4 and 7 in Table 3); and (4) resource supply and sovereignty (objectives 6, 9, 11, 13, 16 and 17 in Table 3); and for the specific objectives of each major category.

A scale from 0 to 10 was used firstly to weight the major categories and, secondly to weight the specific objectives within each category.

In the second round, the objectives were reduced to 19 from the previous 21 and the panelists were asked to answer questions related to their assessment.

Table 3 shows the ranking of weighted objectives, together with an estimation of overlap (∩) among these objectives. Detailed results of this process are shown in Table A-1 in Appendix A.

An average of the estimates, each opinion being equally important, was computed and considered as the estimate of the objectives' relative weight. However, in spite of the Delphi process, considerable dispersion of these values remained. Little improvement was observed in the coefficient of variation of the objectives' relative weight from the first to the second Delphi round. However, this fact seems to be consistent with the value judgement of each participant when assessing mineral policy goals.

The group of objectives related to social-labour considerations shows the highest relative weight: 26. The social-labour group of objectives presents a relative weight of about 8, 11 and 18 percent higher than the relative weights of the ecology group, the resource supply and sovereignty group, and the economic group respectively.

5.1.2.3 Science and Technologies relevant to Mineral Research Program

A list of science and technologies of interest to MRP was discussed with the activity and project leaders. For this list, the MRP Director and activity leaders estimated the criticality of the contribution of the individual science or technology to the achievement of MRP's objectives. A simple averaging of responses was adopted to estimate the criticalities of the sciences and technologies to the objectives. A scale, with values ranging from 0.0 to 1.0 for evaluating the criticality values of the sciences and technologies to the objectives was provided.

TABLE 3

RANKING OF CANMET'S OBJECTIVES: FIRST SCORING MODEL

OBJECTIVE	WEIGHT
1. Ensure occupational health, safety and comfort	7.68
2. Promote further domestic processing	7.64
3. Minimize environmental degradation	7.64
4. Develop more efficient method of winning materials from minerals	7.36
5. Recover, re-use or recycle waste materials	6.67
6. Promote optimum recovery and use from mining, processing and utilization systems	6.54
7. Promote the development of secondary industries based on utilization of mineral products	6.47
8. Promote community stability by extending viable life of mineral operations	5.47
9. Improve the inventory of physical, technical and economic characteristics of earth resources available to Canada	5.27
10. Improve water and soil quality	5.14
11. Promote and encourage the replacement of imports, including equipment, supplies and services	4.74
12. Harmonize mineral-based development with multiple and sequential land use	4.62
13. Substitute abundant for scarce material: identify and develop key sub-marginal deposits	4.58
14. Identify and encourage viable mineral development in areas with insufficient employment opportunities	4.20
15. Meet consumer demands in the provision of mineral based products	4.17
16. Undertake development planning in Northern region territories	3.95
17. Strengthen bargaining position re import of minerals	3.32
18. Promote better regional distribution of income	2.90
19. Obtain a greater share of mineral resource income for social programs	1.64

OVERLAPS

$O_3 \cap O_{10} = 56\%$

$O_4 \cap O_6 = 61\%$

$O_{13} \cap O_{17} = 38\%$

$O_{14} \cap O_{18} = 63\%$

Table 4 shows the list of 62 sciences and technologies and their perceived relative contribution to the achievement of MRP objectives. The chemistry discipline - Organic and Inorganic Chemistry - has the greatest value. On the other hand, the technique Grade Control has the smallest value. Its relative contribution to the achievement of objectives is in a ratio 5.9 : 1. The five major fields (Concentration, Engineering, Earth Sciences, Environmental Control and Chemistry) account for more than 48% of the total criticality score.

The average contribution of basic sciences to MRP's objectives (31.6) is slightly higher than the average contribution of applied techniques to these objectives (29.1). However, the contribution of the whole set of basic sciences relevant to MRP's objectives represents only 34% of the total contribution of the combined set of basic sciences and applied techniques. These results reflect the fact that applied research in particular, as well as basic research, needs to be performed in CANMET to accomplish MRP's objectives.

5.1.2.4 Cost-Effectiveness Results

The Delphi method was not employed to estimate the contribution of project elements to the sciences and technologies, primarily because of time constraints. Given the small number of experts involved in the appraisal of a particular research element, a simple average of the responses was computed. Lower level project supervisors only participated in the evaluation of projects for which they were responsible.

The effectiveness and effectiveness-cost ratio for each project element and project of the MRP's Processing and Mining Activities were calculated. A rank ordering for the project elements and projects of the Mining and Processing activities was obtained using this model. This rank ordering is based on the evaluation of effectiveness-cost (E/C) ratios.

TABLE 4

SCIENCES AND TECHNOLOGIES RELEVANT TO MINERAL RESEARCH PROGRAM AND THEIR RELATIVE CONTRIBUTION TO THE PROGRAM'S OBJECTIVES

FIELD	GROUP	RELATIVE CONTRIBUTION TO THE OBJECTIVES	FIELD CONTRIBUTION TO THE OBJECTIVES
Scientific Discipline			
AGRICULTURE	1. Soil Science	22.5	22.5
CHEMISTRY	2. Organic and Inorganic Chemistry	58.1	
	3. Physical Chemistry	56.2	
	4. Surface and Colloid Chemistry	58.1	172.4
EARTH SCIENCE	5. Crystallography	15.6	
	6. Economic Geology	30.3	
	7. Geophysics	28.5	
	8. Mineralogy	29.6	
	9. Petrography	21.0	
	10. Rock Mechanics	24.2	
	11. Structural Geology	31.3	180.5
MATERIAL	12. Engineering Materials	44.2	
	13. Metallography	41.3	85.7
MATH. SCIENCE	14. Mathematics and Statistics	40.5	40.5
MEDICAL SCIENCE	15. Physiology and Public Health	36.2	
	16. Biology	26.3	62.5
PHYSICS	17. Electricity and Magnetism	15.4	
	18. Fluid Mechanics	10.7	
	19. Solid State Physics	20.2	
	20. Thermodynamics	21.5	67.8

... continued

TABLE 4, continued

FIELD	GROUP	RELATIVE CONTRIBUTION TO THE OBJECTIVES	FIELD CONTRIBUTION TO THE OBJECTIVES
Technologies			
ENVIRONMENTAL CONTROL	21. Waste Disposal	47.7	
	22. Land Reclamation	43.3	
	23. Air Pollution Abatement	43.9	
	24. Waste, Water Treatment	45.6	180.5
ENGINEERING	25. Automatic Control	41.1	
	26. Computer Applications	33.1	
	27. Groundwater and Seepage	32.6	
	28. Electronic and Electrical Engineering	37.0	
	29. Operations Research	40.1	183.9
OPEN PIT	30. Pit Design and Planning Techniques	28.7	
	31. Drilling and Blasting	12.5	
	32. Grade Control	9.8	
	33. Stability Control of Pit Slopes	20.2	
	34. Loading and Transportation Equipment	13.4	84.6
UNDERGROUND MINING	35. Mining Methods	27.4	
	36. Deep Mining Methods	28.2	
	37. Hardrock Continuous Mining Methods and Equipment	24.2	
	38. Hoisting Equipment	13.3	
	39. Raise Driving and Shaft Sinking Equipment	14.3	
	40. Ground Control	24.2	
	41. Working Environment	17.7	
	42. Mining Communication Equipment	16.0	165.5

... continued

TABLE 4 concluded

FIELD	GROUP	RELATIVE CONTRIBUTION TO THE OBJECTIVES	FIELD CONTRIBUTION TO THE OBJECTIVES
Technologies (continued)			
MINING IN SPECIAL CONDITIONS	43. Arctic Mining	37.7	
	44. Deep-Sea Mining	17.8	55.5
CONCENTRATION	45. Comminution	26.6	
	46. Gravity	30.3	
	47. Electrostatic Separation	32.9	
	48. Magnetic Separation	31.3	
	49. Electronic Sorters	30.3	
	50. Flotation	28.6	
	51. Agglomeration	28.3	208.3
HYDROMETALLURGY	52. Leaching	35.1	
	53. Solid/Liquid Separation	48.1	
	54. Solution Purification	48.1	
	55. Metal Recovery	42.4	173.7
PYROMETALLURGY	56. Smelting	35.0	
	57. Roasting/Sintering/Induration	10.1	
	58. Direct Reduction	10.0	
	59. Steelmaking (basic, oxygen or electric)	28.3	83.4
INDUSTRIAL MINERALS	60. Aggregates, Crushed Sands, Cements and Concretes	31.2	
	61. Ceramics and Refractories	38.7	
	62. Fuel Cell and Heat Storage Applications	18.2	88.1

Table 5 shows an example of the effectiveness value and E/C ratio obtained. The E/C ratios of the research elements of the "Complex Zn/Pb/Cu Ores" project are compared with the average E/C ratio for the combined Mining and Processing activities. Eleven project elements have E/C ratios smaller than 4.1 - the average E/C ratio.

If all project elements of the Mining and Processing activities are considered together, then forty research elements - 38% of the total - have an E/C ratio below the average of both activities. Table A-2 in Appendix A shows detailed results for the Mining and Processing activities.

Table 6 summarizes the results for the Mining and Processing activities. The greatest effectiveness values in the Mining activity correspond to the Environment project (2712) and the Open Pit project (2432). However, the Marine Mining project, which has the lowest effectiveness value (154), has the greatest E/C ratio (28.6). This is due mainly to its low annual cost.

Similarly, for the Processing activity, the Inorganic Non-Metallic Materials project and the Zn/Pb/Cu Complex Ores of New Brunswick project have the greatest effectiveness values (2682 and 2170 respectively). However, the Security of Supply project has the greatest E/C ratio (15.4) because of its low annual cost.

The E/C ratio criteria, as shown in Table 6, tends to favour low cost projects. This E/C ratio bias illustrates a particular problem in developing scoring models: the use of adequate scales for estimating the model's parameters. In this case, the results obtained are biased toward the lower cost projects. This is due to the distortion produced when the project cost is measured as an absolute value, but the project's effectiveness is measured as a relative value. Thus, the project cost parameter has a greater impact in the calculation of E/C ratio than the effectiveness parameter.

TABLE 5: COST-EFFECTIVENESS RESULTS FOR THE COMPLEX Zn-Pb-Cu-Fe-S ORES RESEARCH PROJECT

	PROJECT ELEMENT	EFFECTIVENESS	E/C RATIO
1.	Leach Liquor Treatment: Bacterial Leaching	61.4	14.6
2.	Surface and Electrochemical Studies of Sulphides in Relation to Flotation	201.0	13.4
3.	Computer Programs for Analytical Methods in the Chemistry Laboratory	91.2	13.0
4.	Ion Exchange Processes: Bacterial Leaching of Cu-Zn Sulphide Ores	119.5	10.2
5.	Percolation Leaching of Chalcocite-Bornite Ore with Ammoniacal Solutions	114.7	10.1
6.	Recrystallization of Fine-Grained Sulphide Ore by Chemical Transport	79.6	10.0
7.	Mineralogy and Microscope Analysis	30.3	8.0
8.	Percolation Leaching of Chalcopyrite Ore with Ammoniacal Solutions	114.7	6.6
9.	Anodic Dissolution of Lead Sulphides	93.2	6.0
10.	Dissolution of Chalcopyrite in Ferric Ion Media	114.7	6.0
11.	Zinc Electrolysis	100.5	6.0
12.	Ore Characterization	88.4	5.1
13.	ZnS-PbS-FeS Phase Studies	93.1	4.7
14.	Electrochemical Dissolution of Copper Sulphides	93.2	4.7
15.	Percolation Leaching of Pyrite Zn-Pb-Cu Ores with Ferric Ion Media	114.7	3.6
16.	Crystal Structure Studies of Members of the Stannite Family*	86.5	3.3
17.	Crystallography of the Stannite Family*	86.5	3.1
18.	The Role of Chloride Ion and Organic Extractant in the Electro-winning of Co*	42.4	2.8
19.	Computer Programs for Kinetic Studies in the Metallurgical Chemistry Section	33.1	2.5
20.	The Mineralogy, Stoichimetry and Stability Relation of the Stannite Family*	88.4	2.4
21.	Dissolution of Sphalerite in Ferric Chloride Solutions	114.7	2.1
22.	X-Ray Fluorescence on Line Analysis of Pb-Zn Ore Fractions	58.1	1.8
23.	Bacterial Leaching	61.4	1.8
24.	Ore Analysis by Optical Emission Spectroscopy	58.1	1.7
25.	Quantimet Analysis of Base Metal Ores	30.3	0.6
	TOTAL P-1 PROJECT	2,169.5	4.0

* The MRP management decided to include these project elements within the complex Pb-Zn-Cu-Fe-S Ores Project because of their advanced stage of research when the current MRP was defined. The objective of these project elements does not coincide with the MRP's objectives.

TABLE 6: COST-EFFECTIVENESS RESULTS FOR THE FIRST SCORING MODEL

COST-EFFECTIVENESS OF THE MINING ACTIVITY

PROJECT	EFFECTIVENESS	COST $'000	E/C RATIO
Open Pit	2 432	671.8	3.6
Waste Disposal	1 642	175.7	9.4
Underground Mining	725	170.8	4.2
Mining Equipment	497	106.5	4.7
Environment	2 712	517.4	5.2
Marine Mining	154	6.0	28.6
AVERAGE OF THE MINING ACTIVITY	8 162	1 648.2	5.0

COST-EFFECTIVENESS OF THE PROCESSING ACTIVITY

PROJECT	EFFECTIVENESS	COST $'000	E/C RATIO
Complex Ores	2,170	538.7	4.0
Ferrous Extractive	1,205	513.5	2.4
Non-Metallic Materials	2 682	859.9	3.1
Precious and Platinum	714	155.8	4.6
Security of Supply	847	55.0	15.4
AVERAGE OF THE PROCESSING ACTIVITY	7 618	2 122.9	3.6

5.1.2.5 The Effect of Considering the Overlap of Objectives

It was assumed that, for two given objectives, the value of achieving both is given as the sum of the values for the individual objectives. This is valid in the case of independent objectives. However, the objectives in the set considered are not, in fact, independent. Thus, the sum of values for the individual objectives somewhat over-estimates the value of achieving the combined objectives.

An analysis was performed on the effect of considering the overlap of objectives in evaluating the project elements. The weights of the objectives were re-adjusted considering the overlaps of the objectives shown in Table 3 and new effectiveness values were calculated. The approximate method over-estimates values in general. However, values for the activities were never over-estimated by more than 20%.

More importantly, the change in rank order of the project element values was only in respect of a few project elements. For example, in Table 5, the rank order of the project element, Percolation Leaching of Chalcocite-Bornite Ore with Ammoniacal Solutions, previously in the fifth position, resulted in the fourth position after considering the overlap of objectives. In total - for all Mining and Processing activities - project elements presented changes in the rank order.

Table 7 illustrates the effect of using both approximate and exact methods in evaluating projects and activities.

5.1.3 Conclusions

The application of this model to the MRP's activities represents a first attempt to use a systematic and rational model for the evaluation of R&D projects in CANMET. In the analysis of its results, however, some weak points were observed, as discussed below.

TABLE 7: EFFECT OF PERFORMING THE EXACT AND APPROXIMATE CALCULATION OF EFFECTIVENESS-COST VALUES FOR THE FIRST SCORING MODEL

MINING ACTIVITY		APPROXIMATE METHOD		EXACT METHOD	
PROJECT	COST $'000	EFFEC-TIVE-NESS	E/C RATIO	EFFEC-TIVE-NESS	E/C RATIO
Open Pit	671.8	2432	3.6	2053	3.1
Waste Disposal	175.7	1642	9.4	1387	7.9
Underground Mining	170.8	725	4.2	620	3.7
Mining Equipment	106.5	497	4.7	428	4.0
Environment	517.4	2712	5.2	2312	4.5
Marine Mining	6.0	154	28.6	136	25.1
AVERAGE MINING ACTIVITY	1648.2	8180	5.0	6959	4.2

PROCESSING ACTIVITY		APPROXIMATE METHOD		EXACT METHOD	
PROJECT	COST $'000	EFFEC-TIVE-NESS	E/C RATIO	EFFEC-TIVE-NESS	E/C RATIO
Complex Ores	538.7	2170	4.0	1819	3.4
Ferrous Extractive	513.5	1205	2.4	1046	2.0
Non-Metallic Minerals	859.9	2682	3.1	2360	2.7
Precious and Platinum	155.8	714	4.6	597	3.8
Security of Supply	55.0	847	15.4	711	12.9
AVERAGE PROCESSING ACTIVITY	2122.9	7616	3.6	6533	3.1

The relative values of the objectives and the linkage and criticalities of the sciences and technologies for the cost-effectiveness analysis were subjectively estimated. Variation obviously exists in such estimates. However, no attempt was made to assess the variation associated with these estimates. The main reasons behind this decision were the perceived requirement for model simplicity and time restraints.

The errors that could be introduced into the criticalities of science and technologies are the omission of relevant science and technologies and the inclusion of fields that are not, in fact, essential. These errors of omission and commission affect individual project element evaluation. Nevertheless, the overall effect is small due to (1) the small contribution of these science and technologies to the MRP's objectives, and (2) counter-balancing. A review of the model parameters would help to reduce this effect.

Total discounted costs of the projects were not available at the time of evaluation; therefore annual costs were employed to assess E/C ratios. The use of total future costs of project elements discounted at the social rate of discount would certainly improve the evaluation.

No consideration was given to the interdependence among research elements. Very often, however, the success of research work depends upon the result of another research element. In the model employed, the contributions of project elements to the attainment of national goals were evaluated independently and their effects were added. Thus, a project with more project elements has a greater possibility of arriving at a greater effectiveness value.

For two or more given project elements which might contribute to the advancement of a particular science or technology, the contribution of one of them could be more significant than the others if their contribution is marginal. To consider this situation, a full scale should be used instead of two single values.

A more important criticism is that the project elements were indirectly related to national goals through the use of pertinent science and technologies. However, assessing the contribution of a science of technology to national goals is quite a subjective matter and sometimes very difficult.

5.2. Second Scoring Model

A second scoring model was developed in the light of the shortcomings demonstrated by the first model. The second model is derived from the first and utilizes the same basic concepts; however it has a simpler structure wherein the characteristics and diversity of the research activity of the Mineral Research Program are more adequately considered.

5.2.1 Methodology

5.2.1.1 Model Characteristics

The essential mechanism of the scoring technique developed for the MRP comprises a system for rating projects. In this system, the scientific merit of a project is estimated in relation to a set of direct organizational or program objectives which were weighted separately by the MRP managers. A project's scientific merit is expressed in terms of scientific significance and likelihood of technical success and economic viability in anticipated use.

The cost-effectiveness relationship is reduced to an expression which draws together the various parameters. This expression represents a participant's subjective evaluation in the form of a dimensionless effectiveness-cost ratio, as follows:

$$E/C = \frac{pt \times pe \times \sum_{k=1}^{k=n} W_k \times b_k}{C}$$

where

E/C = a non-monetary relative value/cost (effectiveness/cost) ratio for the project;

pt = probability of technical success

pe = probability of economic viability for the results of the proposed (or on-going) research in the foreseeable future;

k = 1, n (n = number of program objectives),

b_k = scientific significance of the research for the k^{th} objective;

W_k = relative weight of the k^{th} objective;

C = R&D project cost.

The average value of the effectiveness/cost ratio ($\overline{E/C}$) for the m participants in the assessment of a project is given by

$$\overline{E/C} = \frac{\left(\sum_{j=1}^{j=m} e_j \times E_j\right) \Big/ \sum_{j=1}^{j=m} e_j}{C}$$

where

E_j = project effectiveness as estimated by participant j

$$(E_j = p_t \times p_e \times \sum_{k=1}^{k=n} W_k \times b_k)$$

e_j = self-rating coefficient of the participant's expertise and knowledge of the scientific and/or technological field of the project; $0 \leq e_j \leq 1$

5.2.1.2 <u>Weighting Organizational Objectives</u>

In the scoring model used previously, no distinction was made between specific CANMET objectives and mineral policy objectives recognized in the government document "Toward a Mineral Policy for Canada - Opportunities for Choice" (1974). To rectify this situation and avoid allocative distortions, direct organizational objectives were separated from the mineral policy objectives.

A set of preliminary objectives deemed relevant to the mission of the MRP, together with an explanation of the reasoning underlying this set, were structured and presented to management. The objectives themselves were offered for refinement and amendment until it was generally agreed that they covered the mission of the MRP and were technically sound.

CANMET management was requested to review the provisional set of organizational objectives, paying particular attention to the criteria for defining objectives in the public budgeting context. Following this stage came the weighting of organizational objectives which was confined to program managers.

Organizational objectives were generated under four broad dimensions believed to encompass the scope of the Mineral Research Program's mission. These dimensions transcend CANMET administrative divisions, i.e. Mining, Processing and Utilization, and thus tend to neutralize disciplinary or administrative bias in ranking or weighting objectives at this level.

In weighting the objectives, management was requested to observe policy directives received from EMR's Planning and Evaluation Office or any other central planning and policy-making authority. Where no explicit directive existed, management was asked to weight according to its own interpretation of the general orientation in government postures on related economic and social issues. As for the specific objectives, management was asked to weight these according to its personal views on the proper balance of research objectives within the Mineral Program. A scale from 0 to 10 was indicated for use in the weighting of Dimensions and Objectives. The results were normalized and average values of the weight of program objectives were considered. Table 8 shows the results obtained in this assessment. Weights are expressed in terms of percentage.

5.2.1.3 Sensitivity Analysis

Information on the marginal change in effectiveness with marginal change in research effort was incorporated in the evaluation model in order to perform a sensitivity analysis.

TABLE 8: WEIGHTING ORGANIZATIONAL OBJECTIVES - SECOND SCORING MODEL

Weight	DIMENSIONS	Weight	OBJECTIVES	OBJECTIVE NUMBER
27	HUMAN HEALTH AND PROTECTION	11	Develop technology to reduce all human diseases and environmental health hazards related to mineral industry activities including non-occupational diseases	1
		10	Develop technology to improve safety from injury in the workplace	2
		6	Develop technology to improve worker comfort	3
22	ENVIRONMENTAL PROTECTION AND HARMONY	22	Develop technology to conduct mineral industry activities and dispose of wastes and effluents in a manner which minimizes conflict with other resources and land uses, including recreational uses	4
28	ECONOMIC EFFICIENCY AND PRODUCTIVITY	6	Develop technology to lower operating costs and raise levels of recovery in mining	5
		6	Develop technology to enable efficient or more efficient processing of minerals for both conventional and unconventional natural resources	6
		6	Develop technology to improve efficiency in metallurgical extractions	7
		6	Develop technology to improve efficiency in semi-fabrication	8
		4	Develop technology to improve secondary recovery from wastes and scrap	9
23	INDUSTRY DIVERSIFICATION	9	Develop technology to improve situations where specific opportunities for further domestic up-grading of minerals and mineral products are seen, or can be foreseen, to be limited by deficiencies in or lack of technology	10
		8	Apply technological research to the development of improved mineral-based products and processes specially where these replace the use of scarce resources	11
		6	Undertake research to find new uses specifically for mineral and metal wastes	12
		100		

This requirement was aimed at acquiring information to indicate, in terms of scientific efficiency, which projects should be cut back under general budgetary contractions and which should be favoured under general budgetary expansions.

Thus, the Marginal Effectiveness/Cost Ratio (MEC) for a change in the level of funding is given by

$$MEC = \frac{\sum_{j=1}^{j=m} \delta pt_j \times pe_j \times e_j \times \left(\sum_{k=1}^{k=n} W_{jk} \times b_{jk} \right) \Big/ \sum_{j=1}^{j=m} e_j}{MC}$$

where

δpt = change in the probability of technical success due to a change in funding;

MC = marginal cost; change in the present value of the project cost.

5.2.2 Application of the Second Scoring Model to the 1978/79 Fiscal Year

A questionnaire was designed and survey participants were asked to relate each project to each objective by indicating (on a prescribed scale) their estimation of the relative scientific significance in light of each objective independently. The probability of technical success and the probability of economic viability were estimated by each participant for each project. Given the assumption that the scientific significance of a project is independent of the level of funding, each participant was asked to estimate the change in the probability of technical success for each project upon a specified marginal (incremental and decremental) change of 10%, 30% and 50% in the established level of effort or funding of the respective project. Finally, each participant was required to estimate a self-rating coefficient for each project of his own expertise and knowledge of the scientific and/or technological field of the project.

5.2.2.1 Cost-Effectiveness Results

Eighteen respondents participated in this survey, five from the Mining activity, six from the Processing activity and seven from the Utilization activity. The meaning of the different subjective estimates was explained to all participants before the survey began. In spite of this, some participants tended to confuse the subjective probability concept with the degree of project achievement. Others showed inconsistency in estimating the model parameters. These responses were excluded from the analysis.

Table 9 shows the results of the cost-effectiveness model for the Mining, Processing and Utilization activities of the MRP. The column "Effectiveness Considering Self-Rating of Participants" indicates the average relative value of each project as estimated by scientists. Projects[1] in the Processing activity generally have higher effectiveness values, their average being 12.2. Projects Nos. 17, 21 and 18 have the highest values: 23.2, 21.8 and 20.0 respectively. Projects in the Mining activity are perceived as having lower effectiveness values, with an average of 8.1. The lowest values are for Projects Nos. 5, 8 and 9 which show 2.6, 3.2 and 3.9 respectively. Projects in the Utilization activity have an intermediate average effectiveness value (10.3).

The column "Effectiveness/Cost Ratio" indicates the effectiveness-cost value of projects. Small projects show higher E/C ratios because of their low costs. The scale used for representing project cost (absolute value) is greater than the scale employed for estimating project effectiveness (a relative value). Consequently, projects with lower costs tend to have higher E/C ratios. However, the E/C ratio for those projects with costs of the same order of magnitude is a useful criterion in the allocation of scarce resources.

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[1] Projects are identified by a number for simplicity of analysis.

TABLE 9: COST-EFFECTIVENESS RESULTS OBTAINED WITH SECOND SCORING MODEL

PROJECT NUMBER	SIGNIFICANCE	AVERAGE TECHNICAL PROBABILITY	AVERAGE ECONOMIC PROBABILITY	EFFECTIVENESS CONSIDERING SELF-RATING	PROJECT COST $	E/C RATIO ($\times 10^{-5}$)	AVERAGE SELF-RATING
Mining Activity							
1	17.3	.83	.72	11.3	52 800	21.4	.76
2	13.2	.71	.63	6.3	112 100	5.6	.76
3	7.2	.91	.79	5.0	15 400	32.4	.87
4	10.7	.83	.68	6.0	79 100	7.6	.80
5	7.8	.53	.74	2.6	5 500	46.4	.27
6	22.8	.85	.59	11.6	50 500	22.9	.80
7	22.8	.78	.65	11.6	41 800	27.6	.80
8	4.8	.82	.73	3.2	46 200	6.9	.55
9	8.5	.83	.54	3.9	13 200	29.5	.55
10	17.2	.86	.71	9.1	847,000	1.1	.65
11	18.8	.87	.68	10.2	93,000	11.0	.55
12	19.5	.75	.77	10.3	58 500	17.6	.60
13	19.8	.62	.72	7.3	46,600	15.6	.53
14	22.5	.67	.66	9.5	103,000	9.2	.50
15	20.4	.83	.53	8.4	65 000	13.0	.50
16	26.6	.79	.58	12.8	220 000	5.8	.50
Processing Activity							
17	35.3	.85	.75	23.2	1 006 000	2.3	.70
18	39.2	.82	.72	22.0	1,673,500	1.3	.73
19	22.5	.78	.57	9.7	70,000	13.9	.70
20	23.4	.71	.49	10.2	23 000	44.5	.50
21	33.6	.84	.69	21.8	1 102,000	2.0	.50
22	47.6	.45	.42	11.7	325,000	3.6	.60
23	24.2	.83	.45	9.7	23 000	42.0	.60
24	32.4	.71	.56	11.5	70 000	16.4	.80
25	20.6	.73	.72	12.5	255 000	4.9	.47
26	20.8	.59	.65	7.2	93 000	7.8	.50
27	16.4	.69	.45	5.3	95 000	5.6	.48
28	10.8	.90	.55	8.2	47 000	17.5	.53
29	14.0	.80	.85	13.1	115,000	11.4	.50
30	23.3	.81	.45	9.9	93 000	10.7	.64
31	16.7	.82	.51	6.5	23,000	28.1	.52
Utilization Activity							
32	11.2	.86	.48	5.6	169 000	3.3	.50
33	16.0	.92	.81	14.3	319 000	4.5	.48
34	20.7	.74	.69	11.4	155 100	7.3	.57
35	14.9	.80	.69	8.6	74,700	11.5	.48
36	12.8	.77	.49	5.5	36 700	15.1	.57
37	23.6	.90	.47	13.1	462 600	2.8	.36
38	11.4	.84	.60	9.2	244,000	3.8	.40
39	14.9	.87	.79	12.9	59 200	21.8	.70
40	15.6	.70	.45	6.9	35,300	19.6	.47
41	22.5	.79	.68	13.3	746,100	1.8	.77
42	19.7	.79	.54	9.5	270 800	3.5	.77
43	16.7	.65	.56	6.6	239 800	2.8	.57
44	17.9	.56	.64	7.9	106 700	7.4	.60
45	18.1	.72	.66	9.3	70,500	13.1	.60
46	20.5	.83	.74	13.8	234,400	5.9	.66
47	19.6	.82	.79	16.6	398,800	4.2	.60

The column "Average Self-Rating" presents an average value for the participant's expertise and knowledge of the scientific and/or technological field of the project; this qualifies the effectiveness and the E/C ratios shown in the previous columns. Thus, for example, the effectiveness value (9.2) and E/C ratio (3.8) of Project No. 38 were evaluated by participants whose knowledge and/or field of expertise were indirectly related (0.4) to that of the project. On the other hand, the effectiveness value (6.0) and the E/C ratio (7.6) of Project No.4 were assessed by participants in the survey whose knowledge and/or field of expertise are directly related (0.8) to that of the project.

The columns "Average Technical Probability" and "Average Economic Probability" indicate the average values of these parameters as estimated by the CANMET participants in the survey. The relatively high values of the projects' technical probability of success correspond partly to the selection process for research proposals that takes place in CANMET. This process involves a number of proposal pre-screenings at different levels of research management responsibility. Also, these high values are partly due to the limited technical objectives fixed for each research proposal. The high values of the projects' economic probability of success seem to indicate that CANMET survey participants have highly biased opinions about the economic viability of the projects. An independent assessment of these parameters by external experts would certainly contribute to reduce this bias.

5.2.2.2. <u>Contribution of Projects to the Achievement of the Mineral Research Program Objectives</u>

Table 10 shows the relative contribution of research activities to the achievement of the MRP's objectives. Projects of the Mining activity contribute more to Objectives 5 (Develop Technology to Lower Operating Costs and Raise Levels of Recovery in Mining), 1 (Develop Technology to Reduce all Human Diseases and Environmental Health Hazards Related to Mineral Industry

TABLE 10: RELATIVE CONTRIBUTION OF RESEARCH ACTIVITIES TO THE ACHIEVEMENT OF MRP'S OBJECTIVES

PROGRAM OBJECTIVES	RELATIVE CONTRIBUTION		
	Mining Activity	Processing Activity	Utilization Activity
1. Develop technology to reduce all human diseases and environmental health hazards related to mineral industry activities, including non-occupational diseases	.35	.26	.04
2. Develop technology to improve safety from injury in the workplace	.15	.08	.13
3. Develop technology to improve worker comfort	.11	.05	.02
4. Develop technology to conduct mineral industry activities and dispose of wastes and effluents in a manner which minimizes conflict with other resources and land uses, including recreational uses	.31	.23	.08
5. Develop technology to lower operating costs and raise levels of recovery in mining	.43	.26	.13
6. Develop technology to enable efficient or more efficient processing of minerals for both conventional and unconventional natural resources	.03	.53	.21
7. Develop technology to improve efficiency in metallurgical extraction	.01	.40	.10
8. Develop technology to improve efficiency in semi-fabrication	.00	.15	.54
9. Develop technology to improve secondary recovery from wastes and scraps	.00	.24	.13
10. Develop technology to improve situations where specific opportunities for further domestic up-grading of minerals and mineral products are seen or can be foreseen to be limited by deficiencies in or lack of technology	.01	.48	.48
11. Apply technological research to the development of improved mineral-based products and processes, especially where these replace the use of scarce resources	.00	.29	.33
12. Undertake research to find new uses specifically for mineral and metal wastes	.02	.19	.08

Activities, including Non-Occupational Diseases) and 4 (Develop Technology to Conduct Mineral Industry Activities and Dispose of Wastes and Effluents in a Manner which Minimizes Conflict with Other Resources and Land Uses, Including Recreational Uses). Their scores are 0.43, 0.35 and 0.31 respectively.

Projects of the Processing acitivity, in turn, contribute more to Objectives 6 (Develop Technology to Enable Efficient or More Efficient Processing of Minerals for Both Conventional and Unconventional Natural Resources), 10 (Develop Technology to Improve Situations Where Specific Opportunities for Further Domestic Up-grading of Minerals and Mineral Products are seen, or can be Foreseen, to be Limited by Deficiencies in or Lack of Technology), and 7 (Develop Technology to Improve Efficiency in Metallurgical Extraction). Their scores are 0.53, 0.48 and 0.40 respectively.

Projects of the Utilization activity make a greater contribution to Objectives 8 (Develop Technology to Improve Efficiency in Semi-Fabrication), 10 (Develop Technology to Improve Situations where Specific Opportunities for Further Domestic Up-grading of Minerals or Mineral Products are seen, or can be Foreseen, to be Limited by Deficiencies in or Lack of Technology), and 11 (Apply Technological Research to the Development of Improved Mineral-Based Products and Processes, Especially Where these Replace the Use of Scarce Resources). Their respective scores are 0.54, 0.48 and 0.33.

5.2.2.3 Effect of Changing the Projects' Level of Funding

The resource re-allocation problem for an expansion or a reduction in the overall research budget is to find the values of the effectiveness variation (ME_i) and cost variation (MC_i), corresponding to each research project, which optimize the objective function Z.

$$Z = \sum_{i=1}^{n} ME_i$$

subject to $\sum_{i=1}^{n} MC_i \leq MCT$ and $ME_i = f_i(MC)$

where MCT = overall budget change.

For a budget reduction the following relationships also hold

$$ME_i \leq E_i \quad \text{and} \quad MC_i \leq C_i$$

This model may be solved by using mathematical programming, providing that the function $ME_i = f_i(MC)$ can be defined. An examination of the effectiveness variation for various levels of change in research project funding reveals that ME_i is not a linear function of MC_i (see Tables B-2 to B-4 in Appendix B).

The problem of optimizing the impact of an overall research budget change on the effectiveness value of the projects is further complicated by the various constraints related to the organization of research and by the nature of the research projects carried out at CANMET. Consequently, a simple ranking based on the marginal effectiveness-cost ratio criterion is provided to help CANMET research management in deciding which projects should first receive additional funding or be cut back under budget reduction circumstances.

Table 11 compares the results of ranking the series of research projects under different criteria: Effectiveness/Cost Ratio and Marginal Effectiveness/Cost Ratio. The purpose of this analysis is to investigate whether or not the research projects are funded at their optimal level and, if not, which projects should first receive additional funding or be cut back.

The comparison reveals a radical change in the order of priority for an expansion in the projects' level of funding when the

TABLE 11: RANKING OF RESEARCH PROJECTS ACCORDING TO DIFFERENT CRITERIA

EFFECT/COST RATIO			MARGINAL E/C (INCREMENT IN PROJECTS' COST)			MARGINAL E/C (DECREMENT IN PROJECTS' COST)		
P#	RO	SRC	P#	RO	SRC	P#	RO	SRC
5	1	.3	31	1	.6	5	1	.2
20	2	.5	13	2	.5	20	2	.6
23	3	.6	12	3	.6	23	3	.7
3	4	.9	39	4	.8	19	4	.7
9	5	.6	15	5	.5	31	5	.6
31	6	.5	35	6	.5	11	6	.6
7	7	.8	11	7	.6	9	7	.6
6	8	.8	26	8	.5	27	8	.5
39	9	.7	14	9	.5	13	9	.5
1	10	.8	16	10	.5	2	10	.8
40	11	.5	2	11	.8	12	11	.6
12	12	.6	30	12	.8	40	12	.6
28	13	.5	24	13	.8	39	13	.8
13	14	.5	20	14	.6	15	14	.5
36	15	.6	4	15	.8	30	15	.8
24	16	.8	22	16	.7	26	16	.5
19	17	.7	44	17	.7	44	17	.7
15	18	.5	36	18	.6	45	18	.7
45	19	.6	17	19	.7	14	19	.5
35	20	.5	43	20	.6	16	20	.5
29	21	.6	18	21	.7	17	21	.7
11	22	.6	38	22	.5	29	22	.6
30	23	.6	1	23	.8	24	23	.8
14	24	.5	3	23	.9	42	24	.9
26	25	.5	5	23	.2	4	25	.8
4	26	.8	6	23	.8	46	26	.7
44	27	.6	7	23	.8	43	27	.6
34	28	.6	8	23	.5	25	28	.5
8	29	.6	9	23	.6	22	29	.7
46	30	.7	10	23	.7	34	30	.6
16	31	.5	19	23	.7	8	31	.5
27	32	.5	21	23	.5	33	32	.6
2	33	.8	23	23	.7	28	33	.5
33	34	.5	25	23	.5	18	34	.7
47	35	.6	27	23	.5	10	35	.7
25	36	.5	28	23	.5	41	36	.9
38	37	.4	29	23	.6	21	37	.5
42	38	.8	32	23	.5	38	38	.5
22	39	.6	33	23	.6	1	39	.8
32	40	.5	34	23	.6	3	39	.9
43	41	.6	37	23	.4	6	39	.8
37	42	.4	40	23	.6	7	39	.8
17	43	.7	41	23	.9	32	39	.5
21	44	.5	42	23	.9	35	39	.5
41	45	.8	45	23	.7	36	39	.6
18	46	.7	46	23	.7	37	39	.4
10	47	.7	47	23	.7	47	39	.7

P#: Project Number
RO: Ranking Order
SRC: Self-Rating Coefficient

Marginal Effectiveness-Cost criterion is used instead of the simple Cost-Effectiveness criterion. Seven projects (Nos. 5, 23, 3, 9, 7, 6 and 1) are included in the top ten under the simple Cost-Effectiveness criteria but change their ranking order to the lowest priority under the marginal criteria. This change reflects the fact that these projects will not increase their effectiveness under conditions of a budgetary expansion in spite of their high effectiveness-cost ratios. Conversely, the ranking order of Projects Nos. 13, 12, 15, 35, 26 and 16 is altered significantly under the marginal criterion. These projects are included among the first ten priorities for an increase in the projects' level of funding because of their high marginal effectivaness values.

On the other hand, project ranking order does not change so radically under a contraction in the projects' level of funding. Five projects included in the ten first priorities according to the simple Cost-Effectiveness criterion are retained in the first ten under the marginal criterion, although in a different order. Projects Nos. 19, 11, 27 and 2 have higher priorities under the marginal criterion, whereas Projects Nos. 3, 7, 6 and 1 have their priorities shifted to the lowest position under the marginal criterion.

For both an expansion and a reduction in the projects' cost level, the marginal effectiveness of the projects with lowest priority - rank order 23rd for a cost expansion and rank order 39th for a cost contraction - has a value equal to zero. This means that the marginal effectiveness is not affected by a marginal change in financing. This situation stems from the fact that either the projects are financed at the maximum possible level, or that the change in input resources used to define marginal values is not enough to modify their outcome. A greater variation in input would be needed to cause a change in the effectiveness value. In contrast, and even more important, projects having higher priorities in an increase of the projects' level of funding ranking seem to be underfinanced with present budget allocations and could, in some cases, improve their effectiveness significantly with a budget expansion.

5.2.2.4 Effect on Project Ranking When Probability of Economic Success Is Not Considered

The effect of not considering projects' economic viability, as represented by their probability of economic success, in determining priorities is shown in Table 12. The ranking order obtained under simple Effectiveness/Cost Ratio criterion and Marginal Effectiveness/Cost Ratio criterion, considering the economic effect of the projects, is contrasted with the ranking order under the same criteria when only scientific and technical merits of projects are considered.

Under the simple Effectiveness-Cost Ratio criterion, only small changes are produced. For example, eight projects are included among the ten first priorities with and without consideration of their economic effect, although the order is different.

In contrast, under the marginal criterion for a 10% budget increase, some significant changes are observed. For instance, Project No. 24 changes its rank order from 13th to 3rd if its economic viability is not considered. Project No.15 changes its position from rank order 5 to rank order 10.

Similarly, significant changes are observed when the marginal criteria for a 10% budget reduction is considered. For example, Project No. 15 changes its rank order from 14th to 6th position if its economic viability is not taken into account. Project No. 24 changes its position from rank order 23 to rank order 4 under the same circumstances.

TABLE 12: **COMPARISON OF RESULTS OBTAINED WHEN THE ECONOMIC EFFECT OF THE PROJECTS IS CONSIDERED, AND WHEN ONLY SCIENTIFIC AND TECHNICAL MERITS ARE CONSIDERED**

THE ECONOMIC EFFECT OF THE PROJECTS ARE CONSIDERED									ONLY SCIENTIFIC AND TECHNICAL MERITS ARE CONSIDERED								
EFFECT/COST RATIO			MARGINAL E/C FOR +10% COST			MARGINAL E/C FOR -10% COST			EFFECT/COST RATIO			MARGINAL E/C FOR +10% COST			MARGINAL E/C FOR -10% COST		
P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC
5	1	.3		1	.6	5	1	.2	23	1	.6	31	1	.6	5	1	.3
20	2	.5	13	2	.5	20	2	.6	20	2	.5	13	2	.6	20	2	.6
23	3	.6	12	3	.6	23	3	.7	5	3	.3	24	3	.8	23	3	.7
3	4	.9	39	4	.8	19	4	.7	31	4	.5	12	4	.6	24	4	.8
9	5	.6	15	5	.5	31	5	.6	40	5	.4	30	5	.8	31	5	.6
31	6	.5	35	6	.5	11	6	.6	9	6	.6	26	6	.5	15	6	.5
7	7	.8	11	7	.6	9	7	.6	3	7	.8	35	7	.6	19	7	.7
6	8	.8	26	8	.5	27	8	.5	7	8	.8	39	8	.7	11	8	.5
39	9	.7	14	9	.5	13	9	.5	36	9	.5	11	9	.5	9	9	.6
1	10	.8	16	10	.5	2	10	.8	6	10	.8	15	10	.5	13	10	.6
40	11	.5	2	11	.8	12	11	.6	24	11	.8	20	11	.6	12	11	.6
12	12	.6	30	12	.8	40	12	.6	1	12	.8	14	12	.5	40	12	.4
28	13	.5	24	13	.8	39	13	.8	28	13	.6	2	13	.8	28	13	.7
24	14	.8	20	14	.6	15	14	.5	39	14	.7	16	14	.5	27	14	.5
13	15	.5	4	15	.8	30	15	.8	19	15	.7	4	15	.7	2	15	.8
36	16	.6	22	16	.7	26	16	.5	13	16	.6	22	16	.7	44	16	.7
19	17	.7	44	17	.7	44	17	.7	12	17	.6	36	17	.5	30	17	.8
45	18	.6	36	18	.6	45	18	.7	30	18	.6	44	18	.7	26	18	.5
15	19	.5	17	19	.7	14	19	.5	15	19	.5	43	19	.6	39	19	.7
35	20	.5	43	20	.6	16	20	.5	45	20	.6	17	20	.7	45	20	.7
29	21	.5	18	21	.7	17	21	.7	35	21	.5	18	21	.7	29	21	.7
11	22	.6	38	22	.5	29	22	.6	11	22	.5	38	22	.5	14	22	.5
30	23	.6	1	23	.8	24	23	.8	14	23	.5	1	23	.8	16	23	.5
14	24	.5	3	23	.9	42	24	.9	29	24	.6	3	23	.8	17	24	.7
26	25	.5	5	23	.2	4	25	.8	26	25	.5	5	23	.3	4	25	.7
4	26	.8	6	23	.8	46	26	.7	4	26	.7	6	23	.8	43	26	.6
44	27	.6	7	23	.8	43	27	.6	34	27	.5	7	23	.8	22	27	.7
34	28	.6	8	23	.5	25	28	.5	44	28	.6	8	23	.6	8	28	.6
8	29	.6	9	23	.6	22	29	.7	8	29	.6	9	23	.6	46	29	.7
46	30	.7	10	23	.7	34	30	.6	27	30	.4	10	23	.6	42	30	.9
16	31	.5	19	23	.7	8	31	.5	16	31	.5	19	23	.7	25	31	.5
2	32	.8	21	23	.5	33	32	.6	2	32	.8	21	23	.5	34	32	.6
27	33	.5	23	23	.7	28	33	.5	22	33	.6	23	23	.7	33	33	.6
25	34	.5	25	23	.5	18	34	.7	46	34	.7	25	23	.5	10	34	.6
33	35	.5	27	23	.5	10	35	.7	32	35	.5	27	23	.5	18	35	.7
47	36	.6	28	23	.5	41	36	.9	38	36	.4	28	23	.7	41	36	.9
38	37	.4	29	23	.6	21	37	.5	42	37	.8	29	23	.7	21	37	.5
22	38	.6	32	23	.5	38	38	.5	25	38	.5	32	23	.5	38	38	.5
42	39	.8	33	23	.6	1	39	.8	33	39	.5	33	23	.6	1	39	.8
32	40	.5	34	23	.6	3	39	.9	47	40	.6	34	23	.6	3	39	.8
37	41	.4	37	23	.4	6	39	.8	43	41	.6	37	23	.4	6	39	.8
43	42	.6	40	23	.6	7	39	.8	37	42	.4	40	23	.4	7	39	.8
17	43	.7	41	23	.9	32	39	.5	17	43	.7	41	23	.9	32	39	.5
21	44	.5	42	23	.9	35	39	.5	21	44	.5	42	23	.9	35	39	.6
41	45	.8	45	23	.7	36	39	.6	41	45	.8	45	23	.7	36	39	.5
18	46	.7	46	23	.7	37	39	.4	18	46	.7	46	23	.7	37	39	.4
10	47	.7	47	23	.7	47	39	.7	10	47	.6	47	23	.6	47	39*	.6

P#: Project Number; RO: Ranking Order; SRC: Average Self-Rating Coefficient

5.2.2.5 Effect of Considering the Self-Rating Coefficient on Project Ranking

Table 13 shows the effect of the participants' self-rating coefficient in obtaining priorities. The rank order resulting from the use of simple Effectiveness-Cost Ratio criteria indicates that some projects have their priorities changed when the self-rating coefficients are not considered. However, these changes are insignificant.

The results obtained by using the Marginal Effectiveness-Cost Ratio criteria - under conditions of a 10% budgetary increment - show greater variations. For instance, Project No.10 and Project No.4 switch their rank orders (2nd and 5th) when the self-rating coefficient is not considered.

The rank order of projects employing the Marginal Effectiveness-Cost Ratio for a 10% budget reduction presents less significant changes. A comparison of results - with and without self-rating coefficient - indicates that the first four rank orders remain unchanged.

5.2.3 Conclusions

The Second Scoring Model provides a useful working tool for developing priorities among MRP projects. Rank orderings for these projects were obtained under different criteria using this model. The following conclusions can be drawn from the present application of this technique.

(1) Effectiveness criterion discriminates against smaller projects and tends to favour major projects. Furthermore, this criterion does not consider how effectively resources are spent.

(2) At the time of the evaluation, estimated future costs of projects were not available. Annual project costs were employed instead in calculating effectiveness-cost ratio.

TABLE 13: EFFECT OF CONSIDERING SELF-RATING COEFFICIENTS ON PROJECTS RANKING UNDER DIFFERENT CRITERIA

CONSIDERING SELF-RATING COEFFICIENTS						WITHOUT CONSIDERING SELF-RATING COEFFICIENTS					
EFFECT/COST RATIO		MARGINAL E/C FOR +10% COST		MARGINAL E/C FOR -10% COST		EFFECT/COST RATIO		MARGINAL E/C FOR +10% COST		MARGINAL E/C FOR -10% COST	
P#	RO	P#	RO	P#	RO	P#	RO	P#	RO	P#	RO
4	1	15	1	4	1	7	1	15	1	4	1
7	2	10	2	7	2	4	2	4	2	7	2
15	3	14	3	3	3	15	3	8	3	3	3
12	4	8	4	15	4	8	4	14	4	15	4
8	5	4	5	11	5	3	5	10	5	14	5
3	6	6	6	14	6	12	6	6	6	13	6
13	7	1	7	10	7	10	7	9	7	11	7
14	8	2	7	1	8	13	8	1	8	1	8
10	9	3	7	13	9	14	9	2	8	10	9
11	10	5	7	8	10	11	10	3	8	8	10
9	11	7	7	9	11	9	11	5	8	6	11
6	12	9	7	6	12	6	12	7	8	12	12
1	13	11	7	12	13	1	13	11	8	9	13
5	14	12	7	2	14	5	14	12	8	2	14
2	15	13	7	5	15	2	15	13	8	5	15

P#: Project Number

RO: Ranking Order

However, given the sequential nature of research projects and the rapidly increasing costs associated with more advanced stages, effectiveness-cost ratios calculated using annual project costs are biased to those projects which are in the earlier stages of research. The use of estimated future costs for projects, discounted at the appropriate social rate of discount, would certainly improve the evaluation. However, these costs are difficult to obtain because of the reluctance of scientists to estimate future inputs to projects. A further complication arises in selecting an adequate social discount rate.

An alternate approach in dealing with project costs would be to express them in relative terms. The development of an appropriate scale for indicating the relative importance of project costs - as perceived by MRP's management - is suggested. Project categories such as (1) very high cost; (2) high cost, (3) medium cost, (4) low cost, and (5) very low cost could be used for this purpose. Due to time constraints, the effect of project costs expressed in relative terms has not been investigated.

(3) Marginal Cost-Effectiveness criterion, used within a budgeting context, provides a more appropriate tool for deciding which projects should be the first to receive additional funding or to be cut back under budget contraction circumstances. This criterion favours only those projects that are more sensitive to budget change. As a result, the bias introduced by project cost size under the simple effectiveness-cost ratio criterion is largely avoided.

(4) The validity of the ranking orders obtained with this model and their usefulness for management decision-making depend, to a great extent, on the cooperation of the project coordinators participating in the assessment. The survey participants'

comprehension of the characteristics and limitations of the model employed is another critical factor in this respect.

(5) The sensitivity analysis preformed shows that, when the economic viability of projects and the self-rating coefficients are not considered in the evaluation, significant departures in project ranking order are produced.

(6) Final reliability of the model was not tested. The model was not applied for a sufficiently long period of time to allow for such a test. Therefore it was not possible at this stage to compare project estimates - provided by the application of the model - with actual project outcome.

CHAPTER 6

THE COST-BENEFIT ANALYSIS APPROACH

Funding research and development is a type of investment where external factors - benefits and costs beyond the decision-maker's control - are usually important. The results of research and development are not easily kept private; usually they are widely disseminated. Hence the social return from scientific research is likely to be greater than the private return to those who have financed it.

The choice of one project over another, from a public sector point of view, must be examined in the context of its relative national impact which, in turn, has to be evaluated in terms of a consistent and appropriate set of objectives. When a project is selected, the choice may have consequences for employment, output, consumption, savings, foreign exchange earnings, income distribution and other factors relevant to national objectives. The purpose of social cost-benefit analysis is, therefore, to determine whether these consequences, taken together, are desirable in the light of national planning objectives.

Cost-benefit analysis is a quantitative evaluation technique for determining which of several courses of action will be the most profitable. It provides a rational framework for project selection, using national objectives and values. Projects are judged in terms of their impact on the economy, and this impact is evaluated by using parameters reflecting national goals. The range of alternatives examined is limited by various constraints such as the size of budget available for investment, the nature of the purpose to be served by a proposed project, and technical feasibility.

6.1 Basic Assumptions and Concepts of Cost-Benefit Analysis

The assessments made in cost-benefit analysis fall into four broad categories:

(1) the estimation of costs and benefits at the time when they occur;

(2) the evaluation of costs and benefits at a common point in time requiring assumptions regarding time preference and the opportunity cost of capital;

(3) the evaluation of risky outcomes;

(4) the evaluation of costs and benefits associated with individuals having different incomes and regions having different incomes.

6.1.1 The Estimation of Costs and Benefits

Benefits and costs are measured on an incremental basis - the value of an increase or decrease in the output level of the unit under measurement. For example, benefits result from an increase in the output of a good or service, as well as from a decrease in the level of environmental pollution.

All specific goods and services are valued on the basis of market prices expected to prevail at the time when costs are incurred and benefits realized. However, a constant average price level is assumed for each project time horizon. Such an assumption neutralizes the impact of any general inflationary or deflationary trend.

If market prices are either distorted (e.g. by taxes or monopoly) or reflect a market disequilibrium (e.g. unemployment or balance of payment problems), corrective action needs to be considered. For example, to avoid biased market prices, all output should be valued without considering indirect taxes and subsidies, in other words, at factor cost.

Direct benefits are measured by the estimated incremental output of the associated good or service, less associated costs. Associated costs are producers' payments for necessary factors of production.

The distinction between direct and indirect benefits is somewhat arbitrary. Nevertheless, projects often yield a net gain to society that is not wholly captured by those that acquire the project output. For example, indirect benefits result from the building of transportation systems necessary for the project. The benefit provided by such facilities is not limited to the service of the project as they will also improve communications and lower transport costs for the whole area. This is likely to result in lower costs for local industry and hence net consumption benefits for the community as a whole. Another externality may occur when research results are adopted by industries other than the one to which the project research was primarily directed.

There may also be external costs that represent a net loss to society. Pollution is a prominent example of this. Changes in existing levels of air, water and land pollution should be measured for their potential effects on the environment. These effects may be expressed in dollar terms, by order of magnitude, or in intangible terms where applicable.

Indirect national benefits are not included in the cost-benefit calculations. Such benefits assume an important role only when a significant portion of all natural resources are projected to be idle over most or all of the project's time-span and when the project will use previously unemployed resources.

The redistribution aspects of a project are important in the regional economy and thus redistributional benefits and costs are normally calculated and submitted as supplementary material. These benefits and costs are not included in project cash flows or final calculations unless redistribution is specifically intended as a prescribed objective. Any expansion in local employment and income, as well as any additional local investment, occurring as a result of the project should be assessed.

6.1.2 The Social Time Preference Rate

Choosing an appropriate discount rate is one of the most difficult and most important problems in the evaluation of public investment projects. The existence of social time preference requires that the present benefit be weighted more heavily than the future benefit in calculating the social value of a project. Thus, the social rate of discount ensures that the time-stream of benefits and costs in one project is properly compared with the time-stream of benefits and costs in all alternative projects.

The social rate of discount may differ from commercial rates of interest for many reasons. There are no compelling reasons why the market rate of interest should be the appropriate rate at which to discount future benefits.

The choice of the appropriate rate of discount is a problem facing all project planners. It is, therefore, a matter of national policy and it would be incorrect to expect the government project analyst to determine the rate. Rather, the social discount rate should be assessed and designated by the central planning agency.

Different approaches have been suggested as acceptable if the social rate of discount is not available. Some analysts recommend the use of the government borrowing rate as an applicable measure of costs. Other analysts treat the social rate of discount as an unknown in the planning problem and recommend ranking projects on the basis of internal rate of return.

6.1.3 The Choice Context

The necessary condition for the adoption of a project is that discounted benefits should exceed discounted costs. The difference between benefits and costs is the net present value, which is calculated at the relevant social discount rate. Formulated in this way, the value of a project is expressible as a unique absolute magnitude, with costs and benefits measured in the same units. In practice, however, this rule will require some modification due to the presence of constraints on the objective function (e.g. capital rationing) and in the light of allowances for uncertainty.

6.1.4 The Effect of Uncertainty

The implications of uncertainty for public investment decisions are controversial and there are several positions on this issue.

(1) One point of view is that risk should be discounted in the same way for public investment as it is for private investment. It is argued that to treat risk differently in the public sector would result in over-investment in this sector at the expense of private investment yielding higher returns.

(2) A second position is that the government is in a better position to cope with uncertainty than are private investors and therefore government investment should not be evaluated by the same criteria used for private markets. In support of this position, it is argued that the government typically undertakes many projects and the net benefits from each are (generally speaking) small relative to the aggregate consumption of the economy. The government should then evaluate investment opportunities according to their expected net present value, using a rate of discount equal to the social discount rate. Nevertheless, it is probably correct to assume that only under exceptional circumstances is the expected net present value rule appropriate in the context of a regional distribution objective. For example, the failure of a project may have particularly damaging consequences for the region in which it is located. Thus, the simple expected net present value rule would not be sufficient for evaluating net regional benefits. It appears reasonable, up to a point, to reward projects with a relatively certain outcome (i.e. with a small variance) even if they have a lower

expected income (hence lower expected net present value). One suggested method for dealing with such cases is to use the Monte Carlo simulation technique to simulate possible variations of outcomes.

6.1.5 Redistribution of Income

A government has several means of redistributing income: fiscal policy, taxes and subsidies. But to assume that the desired redistribution of consumption is to be achieved independently of projects is to place undue reliance on fiscal policy - taxes and subsidies - and on the pricing policies used in the distribution of the outputs of public enterprises.

A government may express its redistribution objectives by attaching some positive weight to the net benefit accruing to the more deserving group(s) and/or by attaching some negative weight to the net benefit accruing to the less deserving group(s).

Whether the net benefits accruing to a particular region are consumed or invested, a portion will be re-spent within the region. To the extent that this spending results in a net transfer of wage or profit income from elsewhere in the economy to the project region, it will result in additional benefits to the region. For example, the expenditure arising from incomes earned on the project may draw small business and services into the area. The income of these enterprises is now earned in the project region and contributes to the redistribution of benefits in its favour. Such a chain of indirect benefits can, in principle, continue indefinitely, with the benefits on each successive round progressively declining.

In practice, one may well have to abandon the attempt to measure the economy-wide redistributional consequences of a given project and concentrate simply on its major impact on the local region and local groups. For example, it is usually possible to assess fairly accurately the consequences of consumption benefits and costs, or cash transfers, which are confined to the project region and affect solely a well-defined group within that region. Thus, the employment of labour on a project or the consumption of the project output by local consumers involves readily-measurable redistribution effects. But it is generally very difficult to isolate such benefits and costs or cash transfers since they affect the economy as a whole.

6.2 A Cost-Benefit Analysis for Mining Research Projects

The use of cost-benefit analysis has been suggested in recent times to help assess priorities in relation to mineral R&D projects.[1] It has been proposed to evaluate alternative applied research projects that require a long time commitment and sizable amounts of resources for completion.

The cost-benefit methodology developed in this chapter is intended for applied research, which normally has a specific goal such as the more efficient utilization of a scarce resource, increased utilization of an abundant resource, or reduction in environmental pollution. The potential benefits of an applied research project can be predicted and evaluated because of a reasonable degree of certainty as to its extent and area of impact and because of the relatively short time-span between performance of the research and implementation of the results.

Difficulties exist in estimating in advance the cost of research and the scientist may resist estimating project completion time. This is particularly true in the earlier stages of projects. However, if only the major steps likely to be necessary in a research program are predicted, then it is possible to estimate the cost of reaching a given objective. Even though this estimate is subject to inaccuracies and statistical variations, it is likely to be adequate for most cost-benefit calculations.

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[1] See Sprague (1969) and Robinson (1975)

6.2.1 Evaluation and Selection of Mining Research Projects

Sequentiality in decision-making is an inherent characteristic of the R&D process. Conceptual changes from the idea stage to the production stage are noted in the course of an applied research project. A continuous improvement in the quality of data available is observed during the various project stages.

When using single evaluation models, a contradiction is observed: i.e. the same tool is used for varying conditions such as levels of R&D cost, time needed, and degree of risk and uncertainty at a given stage. As a result, the technique does not always fit the need. Since each stage has certain distinctive characteristics, a useful criterion is to associate the evaluation factors with evaluation methods adequate to each stage (Albala, 1975).

On the other hand, the economic outcome of a mining research project is greatly influenced by broad economic and non-economic forces interacting with the innovation process in the mining industry. Thus, the specific characteristics of the mining research process, discussed in Chapter 1, need to be considered in order to develop some analytical methods to guide R&D investment in the mineral industry. Essentially, (1) mining research is generally process or operations oriented; (2) the industry output is a commodity with almost no product differentiation and there is low uncertainty in the future specification of products; (3) given the high R&D cost, laboratory conditions are either of the small batch type or closed circuit recycling. Information provided in this way is highly uncertain.

The following criteria are proposed to select the proper analytical method for each stage: (1) the method must suit the specific characteristics of the particular stage; (2) the evaluation factors selected and the answer demanded must be commensurate with the quantity and quality of available data at each pre-stage evaluation point; and (3) the rigor of the evaluation technique should increase with the increase in magnitude of resources demanded.

The highest level of uncertainty of the outcome of a research project is in its earliest stage of development. Thus, detailed numerical estimation of total research cost, capital cost and market specifics to be employed in complex mathematical models, appears to be an unnecessary investment of time and other valuable resources.

Moreover, in order to deal with this uncertainty and to cope with the pressure of limited time and information, two or more approaches towards realization of the objective may be continued in parallel until a clear choice between them can be made. Such a strategy could provide better information for a decision, maintain options, or hedge against the occurrence of an unsatisfactory outcome. The alternative to a parallel strategy is to pursue the best evident approach, with other possibilities to be pursued only if the first proves unsuccessful. A simple economic model can be constructed for choice between parallel and sequential strategies.

Economic models which consolidate the various quantitative elements into a single value (e.g. net present value or rate of return) are recommended for the evaluation of early stage projects.

As the project progresses and its scope is enlarged, there is a progressive increase in accuracy in the data employed to determine the technical parameters (operating cost, equipment size, grade of product, long-term continuous running reliability), commercial parameters (market size, prices), financial and economic values (investment size, profitability). Naturally, the most accurate data are available at the end of the R&D process, i.e. when the project is ready for commercial implementation and the degree of uncertainty is at its lowest.

It follows, then, that the more complex models are more useful in the advanced stages of the project. The risk analysis model using a Monte Carlo simulation technique appears appropriate to deal with the evaluation of advanced stage projects.

The project selection is based on the model described by Hertz (1964) which systematically combined probability estimates associated with possible outcome values. Thus, an overall view of all projects evaluated is obtained and projects are more adequately related to one another along risk and profit dimensions.

6.3 Case Study #1 - The New Brunswick Complex Base Metal Ores Research Project

This case study illustrates the nature of the calculations described earlier in this chapter. An expenditure of public funds is examined to determine if the development of a new process for treating the complex base metal ores of New Brunswick is justifiable on economic grounds.

This assessment is carried out following completion of the bench scale research stage for three prospective process alternatives. At this point, a decision needs to be made on whether or not to invest public funds in a pilot plant stage of research and, if so, which process alternative yields the highest social return.

6.3.1 The Zinc/Lead/Copper Mining Industry of New Brunswick

The Bathurst-Newcastle area of New Brunswick is well known for its large pyritic base metal deposits. Known major deposits contain about 250 million tons of ore. Approximately 90% of these reserves are in six major deposits, the balance being in sixteen much smaller ones. Brunswick Mining and Smelting (BMS) Nos.6 and 12 orebodies and the Heath Steele (HS) Little River Deposit are now producing. Other major deposits are: Anaconda Caribou, which has been in production but has closed down due to metallurgical problems; Chester; Half-Mile Lake; Murray Brook; Middle Landing and New Landing.

Strata of the same age occurring in south-west New Brunswick may also have potential for deposits of this type. Ores of this type are not confined to New Brunswick: other Canadian fine-grained sulphide deposits are the Errington and Vermilion deposits in Ontario and the Swim Lake, Vangorda Creek and Howard's Pass deposits in the Yukon.

For large tonnage of fine-grained zinc/lead/copper/silver sulphide ore in the Bathurst region of New Brunswick and elsewhere in Canada, the mineral processing technology presently in use cannot efficiently recover the contained metal value. Current flotation practice results in losses of approximately 35 to 45% copper, 30% lead, 15 to 20% zinc and 35 to 50% silver to the tailings. Since the minor base metals in the copper, lead and zinc concentrates are not paid for, the overall recoveries of copper, lead and zinc, even allowing for some reported improvements, are in the order of 50%, 60% and 75% respectively. The root of the difficulty is in the complex intergrowth of the ore minerals in massive pyrite (Gow, 1972).

The BMS and HS companies are able to mine their deposits profitably in spite of the high losses. However, metallurgical shortcomings of known technology have resulted in one mine (Anaconda Caribou) ceasing operations and in other mines not being developed because of unfavourable economics.

Much work has been done by industry to improve flotation recoveries. Some success has recently been reported on the refloating of tailings to recover some of the lost zinc. In spite of such progress, there is a need for further improvement. Solution of the Bathurst ores treatment problem would significantly increase the amount of metals that could be recovered economically.

Production of zinc, lead and copper accounts for over 75% of all New Brunswick mineral output. Zinc production alone represents more than 60%. Mineral production represents about 7% of the total net value of commodity production in the province.

At present, all zinc is exported overseas as concentrate. Lead concentrates from the BMS company go to the Belledune smelter in New Brunswick; those from Heath Steele go to Europe. Copper concentrate is sold to the Gaspé smelter in Quebec.

A market analysis for zinc prepared for the BMS company has forecasted that, commencing in 1980, there will be a market for the sale of an additional 100 000 metric tons of zinc metal production from eastern Canada. However, preliminary studies have indicated that a zinc reduction plant (employing the dead roast conventional technology) is not economical at present under competitive international conditions. Thus, the building of a proposed electrolytic zinc plant has been postponed.

6.3.2 Government Interests

The depressed state of New Brunswick and the particularly high unemployment rate is a cause of serious concern to the Canadian government. The problem arose from a slowdown in the rate of growth in economic activity, coupled with a high rate of growth in the labour force. In 1975, the three thousand new jobs available in the province were less than one third of the increase experienced by the labour force.

The closing down of the Anaconda Caribou operation due to metallurgical difficulties was a serious blow to an already weak area economy. Increased mining activity in the area is obviously desirable, but this depends to some extent on the development of improved metallurgy. From a conservation viewpoint, the high losses resulting from present flotation practice represent a serious concern.

One means of increasing the contribution of the zinc/lead/copper mining industry to the New Brunswick economy specifically and the Canadian economy in general is through the development of a process (or processes) to increase significantly the overall recovery of the metal content of the complex New Brunswick ores. Accordingly, in

1972 the Government of Canada studied the possibility of developing an economically successful new process (Gow, 1972).

In view of the feasibility study undertaken by the BMS company in 1976 on a conventional zinc refinery, it was decided to have at least preliminary technical and economic evaluation data available on alternative processes. These potential alternatives would, therefore, be duly considered before a decision on a zinc refinery for the BMS company was realized. Thus, a parallel research strategy was undertaken due to time constraints.

Three alternative processes have been investigated since that time and the results obtained for the bench scale research stage have recently been reported. The new processing alternatives are:

(1) the Dry-Way Chlorination Process developed by CANMET (Kelly, 1978);

(2) the Sulphation Roast Process developed by the Research and Productivity Council of New Brunswick (Research and Productivity Council, 1978);

(3) the application of the Sherritt Pressure Leaching process to New Brunswick zinc/lead concentrates (Sherritt Gordon Mines Ltd., 1978).

A brief description of these processes is given in Appendix C.

At this point, a decision needs to be made on whether or not to invest public funds in a pilot plant stage of research and, if so, which process alternative yields the highest social return. Consequently, a cost-benefit analysis of a pilot plant investment is developed by the author to provide guidance in these matters.

6.3.3 Assumptions and Methodology

For the purpose of an economic assessment, the author assumed in this study that a new processing technology, successfully developed, is primarily used for the treatment of the New Brunswick complex base metal ores. This technology could later be applied to the treatment of similar ores occurring elsewhere in Canada - ores which are not economical under present technological conditions.

A marginal analysis is performed by the author to compare the present situation in New Brunswick - all minerals sold in concentrate form - with the benefits and costs arising from an improved processing situation. Thus, an investment either in the construction of a conventional technology plant (Dead Roast Zinc refinery) or in the pilot plant and further construction of any of the three alternate processing plants employing new technology is analyzed.

For this purpose, it is assumed that concentrates are purchased from mining producers at a price equal to 30% of the value of the metal content in the concentrates. This concentrate price is assumed to be sufficiently high to encourage the production of bulk and/or tailings refloat concentrates by the existing and/or potential producers and, in this way, to return a profit to the mine/mill operations.

It is assumed that the mineral industry will implement or accept the results of the pilot plant research stage only if the required investment promises to yield a rate equal to, or greater than, what is considered the normal rate of return available from alternative investment opportunities. It is assumed that a 15% before-taxes rate is representative of the private sector. It is also assumed that a processing plant using a new technology would be financed by a domestic corporation.

On the other hand, from the public sector point of view, an investment of public funds in a pilot plant research project should yield a rate of return equal to, or greater than, the social rate of return. For the purpose of this study, the social rate of return is assumed to be 10%. Two expected rates of return are calculated for each alternative. One uses only direct benefits and costs (including research costs) and the other includes indirect benefits and costs as well.

A base case is structured for the purpose of analysis and comparison of the different processing technologies. The author assumes that there will be adequate concentrates available to feed a new processing plant located in New Brunswick producing 100 000 tons of zinc annually for 15 years. Because of the cyclical nature of zinc markets, the plant is expected to operate on an average of 90% of designed capacity.

Input parameters for this base case - capital cost, operating cost and revenue - are represented as split-normal distributions. It is also assumed that revenue and cost do not change with time. A Monte Carlo simulation technique is used to evaluate the effect of uncertainty on the profitability of the different project alternatives. Thus, the risk involved is estimated as the probability of the rate of return: (1) a 15% rate of return is assumed to be the required before-tax minimum for a commercial operation, and (2) a 10% rate of return is assumed to be the social rate of return. A two-year period is considered for the pilot plant research stage, followed by a four year pre-production period.

6.3.4 Estimating Costs and Benefits

All benefits and costs associated with the development and operation of a processing plant using alternate technology are assessed and presented below. Detailed values are given in Appendix C. Also, in order to eliminate inflation effects, mid-1978 constant dollar values are used in the project evaluation.

Revenues for each processing alternative are shown in Table 14. Estimates are based on available data. The metal prices are assumed to be: \$0.32/lb.[1] for zinc and lead; \$0.62/lb. for copper; \$5.40/troy oz. for silver; and \$2.25/lb. for cadmium. Since the sulphuric acid market is volatile and the transportation of acid difficult and costly, it is expected that the net revenue after transportation costs would be \$5/tonne.

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[1] One pound = 0.45359237 kg.

TABLE 14: REVENUE ESTIMATES FOR A 100,000 TONNE ZINC PROCESSING PLANT*

PLANT/TECHNOLOGY	REVENUE MOST LIKELY VALUE (1978 mil.$)	95% CONFIDENCE LIMITS LOWER LIMIT (1978 mil.$)	UPPER LIMIT (1978 mil.$)
Dead Roast Process	67.6	64.2	71.0
Dry-Way Chlorination Process	89.2	75.6	93.6
Pressure Leaching Process	83.7	71.1	89.6
Sulphation Roast Process	93.7	79.6	98.5

* These estimates are based on the output uncertainty of the zinc processing plant. Current metal prices were used in a parametric form in the estimation of the plants' revenue. A sensitivity analysis was performed subsequently to investigate the effect of metal price changes.

Capital costs are estimated from available data.[1] The values obtained are presented in Table 15. Details of the estimation are shown in Appendix C. Operating costs are shown in Table 16. The costs of the pilot plant research stage are estimated to be $4 million and are distributed evenly over a two-year research period.

An increased mining activity in the area of construction of the new plant represents an indirect benefit - possibly about $1.5 million per year. Present uneconomical zinc/lead/copper deposits might be brought into production and the operators would be able to sell their concentrate to the plant.

The development of a new processing technology will increase the possibility of economically exploiting complex zinc/lead/copper ore deposits in other provinces, which are not economical using present processing technology. Table 17 shows estimates of the recoverable value from fine-grained sulphide ores over and above those exploited at present.

The capital cost estimates for the different processing alternatives include environmental control and waste treatment equipment. As a consequence, these processing alternatives improve the existing hygenic and environmental control aspects of the base metal complex ore treatment. However, due to the highly corrosive and toxic nature of the chlorine gas employed in the Dry-Way Chlorination process, the risk of a potential contamination by accident is relatively high. This increased risk is a cost - possibly about $1 million - in terms of injury and loss of life, lost production and the evacuation of people from the contaminated area.

A processing plant for the treatment of base metal complex ores affects a wide range of components in the regional economy. For example, a new processing plant would stimulate the opening of new zinc/lead/copper mines which could be developed in the region. The multiplier effect would be reflected through increased sales

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[1] Kelly (1978), Research and Productivity Council (1978) and Sherritt Gordon Mines Ltd. (1978).

TABLE 15: CAPITAL COST ESTIMATES FOR A 100,000 TONNE ZINC PROCESSING PLANT

PLANT TECHNOLOGY	CAPITAL COST MOST LIKELY VALUE (1978 mil.$)	95% CONFIDENCE LIMITS	
		LOWER LIMIT (1978 mil.$)	UPPER LIMIT (1978 mil.$)
Dead Roast Process	136.1	129.2	163.3
Dry-Way Chlorination Process*	132.6	114.5	172.2
Pressure Leaching Process	118.0	82.6	153.4
Sulphation Roast Process	164.0	123.0	205.0

* The values represent capital cost estimates for chlorination and first stage oxidation reactor units of 30, 60 and 180 min. retention time. These estimates are expected to be within ±30% of the actual cost (at 95% confidence limits).

TABLE 16: OPERATING COST ESTIMATES FOR A 100,000 TONNE ZINC PROCESSING PLANT

PLANT TECHNOLOGY	OPERATING COST MOST LIKELY VALUE (1978 mil.$)	95% CONFIDENCE LIMITS	
		LOWER LIMIT (1978 mil.$)	UPPER LIMIT (1978 mil.$)
Dead Roast Process	21.8	20.7	26.2
Dry-Way Chlorination Process**	19.4	18.1	22.2
Pressure Leaching Process	25.9	18.2	33.6
Sulphation Roast Process	26.0	19.4	32.6

** The values represent operating cost estimates for chlorination and first stage oxidation reactor units of 30, 60 and 180 min. retention time. These estimates are expected to be within ±30% of the actual cost (at 95% confidence limits).

TABLE 17: FINE-GRAINED Zn-Pb-Cu SULPHIDE DEPOSITS

ORE DEPOSIT	Cu	Pb	Zn	Ag	VALUE (mil.$)
New Brunswick non-producers					
(known deposits) (tons of metal)	619 005	1 590 268	3 895 262	113,096,100 (oz)**	
Recoverable metal (tons)	473 539	1 216 555	2,979,875	86 518 517 (oz)	
$ Value* (millions)	646	856	2098	467	4067
Non-producers (remainder of Canada)					
Errington & Vermillion, Ont. (tons)	167 400	133 650	522 450	21 465 000 (oz)	
Swim Lake, Yukon (tons)	-	200 000	275 000	7 500 000 (oz)	
Vangorda Creek, Yukon (tons)	28 200	300 000	466 000	16 544 000 (oz)	
	195 600	633 650	1 263 450	45 509 000 (oz)	
Recoverable metal (tons)	149 534	484 742	966 539	34 814 385 (oz)	
$ Value* (millions)	204	341	680	188	1413
Howard's Pass, Yukon (large tonnage = 100m plus)	8-9% Average Pb-Zn				≈5000
Total $ Value (Millions)					≈10000

* Mining dilution = 0.9; Expected Overall Recovery = 85%;
Metal prices: Zn = $0.32/lb; Cu = $0.62/lb; Ag = $5.4/troy oz.

** One ounce (troy) = 31.10334 grams.

in supplies and services. Employment in the area would be increased in both the processing complex and the regional service sector. The processing plant would provide employment for 440 people and it is projected that another 150 jobs would be created in the service sector plus an additional 150 jobs resulting from accelerated economic activity in the region. The total job generation effect of a new processing plant is thus projected as 740.

The potential jobs created by the project would result in a reduction of unemployment payments in the region. It is projected that, from the 740 new jobs in the region, 500 people living in the area will find employment and of these 250 (50%) could be assumed to come off unemployment. By assuming an annual average of $4,700 in unemployment payments, the total estimate for annual benefits through a reduction of unemployment is possibly about $1.2 million.

The increased industrial sophistication gained by the labour force in the region represents another benefit. Operating experience on a managerial as well as technical level is an important input and requirement in any economic activity, and operating experience beyond the primary extractive stage is highly desirable. A project of this nature, involving new technology, would, if successful, make a major contribution to "know-how" on such matters as productivity of Canadian labour, maintenance and operating experience.

6.3.5 Economic Evaluation

Given the value of benefits and costs previously assessed, it is now possible to calculate the research project's profitability. Since the project is a private-sector one, its profitability will, in the last analysis, determine whether it will be undertaken. If the private sector does not consider the project sufficiently profitable, it might be in the national interest to stimulate interest in it.

Table 18 lists the expected before-tax commercial rate of return for each technological alternative, together with an estimate of the risk involved. Risk is calculated as the probability of the rate of return for the project being less than a 15% rate of return available from alternative investment opportunities.

TABLE 18: EXPECTED RATE OF RETURN AND ASSOCIATED RISK FOR THE PRIVATE SECTOR

PLANT TECHNOLOGY	EXPECTED BEFORE-TAX RATE OF RETURN	PROBABILITY OF THE RATE OF RETURN BEING LESS THAN 15%
Dead Roast Process	5.8%	100.0%
Dry-Way Chlorination Process	18.9%	15.5%
Pressure Leaching Process	13.5%	40.0%
Sulphation Roast Process	14.7%	38.3%

The Dry-Way Chlorination process presents the most favourable conditions: the highest expected rate of return and the lowest probability of the rate of return being less than 15%. On the other hand, the results for the Dead Roast process show the most unfavourable conditions in terms of expected rate of return and associated risk. The values obtained for the Pressure Leaching process and the Sulphation Roast process are also below the 15% rate of return level.

Thus, the analysis of the results indicates that a processing plant for a complex ore from New Brunswick under the given price system is an unattractive venture by commercial standards, except in the case of a Dry-Way Chlorination plant which looks profitable from a private point of view. Whether the development of a new processing alternative is profitable enough to attract investors is open to question since there are a number of disincentives for a mining company to use new technology (as discussed earlier, in Chapter 1). These disincentives are, in particular, high capital costs and a high level of performance uncertainty.

In consequence, a different expected commercial rate of return and associated risk are calculated on the assumption that the research cost is financed by the public sector. Table 19 gives the values obtained.

TABLE 19: EXPECTED RATE OF RETURN AND ASSOCIATED RISK FOR THE PRIVATE SECTOR: COST OF R&D NOT CONSIDERED

PLANT TECHNOLOGY	EXPECTED BEFORE-TAX RATE OF RETURN	PROBABILITY OF THE RATE OF RETURN BEING LESS THAN 15%
Dead Roast Process	5.8%	100.0%
Dry-Way Chlorination Process	20.0%	10.3%
Pressure Leaching Process	14.4%	31.9%
Sulphation Roast Process	15.5%	29.6%

The Dry-Way Chlorination process is the best alternative, both in terms of the expected rate of return and its associated risk. The Sulphation Roast process is the second best choice. Its expected rate of return is slightly higher than the 15% required profitability level, but its associated risk is relatively high, with a 29.6% probability of the rate of return being less than 15%. The economic results for the Pressure Leaching process, although less attractive than the previous two alternatives, is very close to the required 15% profitability level.

Table 20 shows the project's expected rate of return and associated risk for the public sector. These results do not differ much from those indicated for the private sector in Table 19. Thus, the Dry-Way Chlorination process represents the best economic alternative. However, the results given for the Pressure Leaching and Sulphation Roast processes are relatively close to those given for the Dry-Way Chlorination process and besides their expected rates of return are also higher than the assumed social rate of discount. Moreover, these processing alternatives present a low social risk in terms of the rate of return being less than the assumed social rate of discount.

TABLE 20: EXPECTED RATE OF RETURN AND ASSOCIATED RISK FOR THE PUBLIC SECTOR

PLANT TECHNOLOGY	EXPECTED BEFORE-TAX RATE OF RETURN	PROBABILITY OF THE RATE OF RETURN BEING LESS THAN 15%
Dead Roast Process	7.5%	85.7%
Dry-Way Chlorination Process	19.4%	1.6%
Pressure Leaching Process	14.8%	7.3%
Sulphation Roast Process	15.6%	4.2%

Table 21 shows the effect of increasing metal prices on the expected rate of return and its associated risk. This sensitivity analysis was necessary to investigate the effect of changing metal prices, since these input parameters were treated in a parametric form. This was due to the fact that no information on the metal price frequency distributions was available to the author at the time of the evaluation. Increasing metal prices by 10% augments the project's rate of return by 17% for the Dry-Way Chlorination process, 21% for the Pressure Leaching process, 17% for the Sulphation Roast process and 35% for the Dead Roast process. On the other hand, increasing metal prices by 30% adds to the project's expected rate of return by 47% for the Dry-Way Chlorination process, 60% for the Pressure Leaching process, 51% for the Sulphation Roast process and 83% for the Dead Roast process.

TABLE 21: EFFECT OF INCREASING METAL PRICES ON THE EXPECTED RATE OF RETURN AND ASSOCIATED RISK: PRIVATE SECTOR

PLANT TECHNOLOGY	+ 10% METAL PRICES: EXPECTED BEFORE-TAX RATE OF RETURN	+ 10% METAL PRICES: RISK (Pr.<15%)	+ 30% METAL PRICES: EXPECTED BEFORE-TAX RATE OF RETURN	+ 30% METAL PRICES: RISK (Pr.<15%)
Dead Roast Process	10.1%	100.0%	13.7%	64.9%
Dry-Way Chlorination Process	22.8%	5.5%	28.5%	1.4%
Pressure Leaching Process	17.9%	18.2%	23.7%	4.4%
Sulphation Roast Process	18.2%	13.6%	23.6%	2.7%

The effect of potential difficulties in the early period of processing plant operations is examined for the Dry-Way Chlorination process. If production levels for the first three years of operation, before reaching a normal level, are 60%, 80% and 90% respectively, then the expected before-tax rate of return decreases by 41%, that is from 20.0% to 11.8%, and its risk level increases accordingly from a 10.3% probability of the rate of return being less than 15% to a risk level of 57.1%, expressed in the same terms. The project, therefore, becomes an unattractive venture from the private sector point of view.

The effect of a higher concentrate purchase price is examined for the Dry-Way Chlorination process under conditions of production difficulties mentioned before. It is found that, for a 10% higher concentrate cost, the expected rate of return decreases to 9.8%, with an associated risk level of 71.8%.

6.3.6 Comment on the Results

The results indicate that the conventional technology for treating complex metal ores - the Dead Roast process - is uneconomic for the given environmental parameters.

All new processing technologies considered in this study are better economic alternatives than the process employing conventional technology. The Dry-Way Chlorination process presents comparative advantages, in terms of higher expected rate of return and lower level of risk, as compared to the Pressure Leaching process and the Sulphation Roast process.

Since any new technology will be used by the private sector, corporate preferences about the expected profitability and the risk associated with these new technological process are essential for the future adoption of any of these technologies. Thus, the Dry-Way Chlorination process is the only alternative that presents a chance of profitability exceeding the minimum level acceptable to the private sector. Nevertheless, its profitability does not seem high enough to induce private investors to develop the new processing technology. The reason for this risk adversion shown by mining companies to new processing technologies was discussed earlier.

A cost-benefit analysis was performed to study the effect of public financing for a pilot plant research stage. The results indicate that the expected rate of return is higher than the social rate of discount for all the new processing alternatives considered. In addition, their associated level of risk is relatively low. Consequently, the investment of public funds in a pilot plant stage of research is fully justifiable on economic grounds.

On the other hand, if the research costs are not financed by the private sector, a commercial cost-benefit analysis - only direct costs and benefits - shows that the expected rate of return for the best alternative - the Dry-Way Chlorination process - increases about 6% (i.e. from 18.9% to 20.0%), and that the level of risk decreases. Hence the adoption of a new technology by the private sector is more likely.

Variations in the different environmental parameters affect the final outcome markedly, and it is important to stress the high uncertainty associated with these parameters. For example, an increase in metal prices has a strong effect on the expected profitability and its associated risk of a new proposed technology. A 10% metal prices increase results in a 17% increase in the expected rate of return for the best economic alternative.

The effect of possible technical troubles in the early period of operation of any of these new processing technologies cannot be over-emphasized. For example, the expected rate of return for the Dry-Way Chlorination process decreases, under the given assumptions, from 18.9% to 11.8%, making the project uneconomical from a private sector point of view.

6.4 Case Study #2 - The Pit Slope Research Project

The purpose in presenting this case study is to illustrate and discuss an actual application of the cost-benefit analysis approach for mining research projects. It is based on a current research project being conducted by CANMET.

6.4.1 Background

The starting point for considering research on rock slopes was provided by the following questions. Is an improved pit slope design approach, which could replace the safety factor concept, worthwhile? If so, what should the level of financial support required for the successful development of an improved pit slope design approach be? Given these considerations, studies were undertaken at CANMET and, subsequently, a comprehensive Pit Slope Research Project was proposed by CANMET for Treasury Board approval.

As a preliminary evaluation of the project, a social cost-benefit analysis of the R&D effort was conducted (Coates and Dubnie, 1971). The analysis indicates that increasing pit slope could result in large savings in mining costs, and a very high ratio of tangible benefits to cost was estimated. This cost-benefit analysis was obviously quite influential in winning Treasury Board support and conditional approval.

Following approval in principle in June 1971, a briefing session with representatives of industry and government departments was arranged, and invitations to tender for the work were sent to interested organizations. An interdepartmental selection committee chose the successful contractors, and contract negotiations were completed by the end of 1971. Official notification of Treasury Board approval for implementation was given on March 9, 1972, contracts were signed, and work started on April 1, 1972.

The Pit Slope Research Project entails two five-year phases of execution. The first phase, which was completed in 1977, involved preparation of a comprehensive engineering manual for the design of open pit mine slopes and support systems. The second phase, now in progress, consists of conferences, industry seminars and company workshops. This phase attempts to explain to users the design methods which have been developed. Transfer of technology to private industry and its diffusion throughout the industry is the objective.

6.4.2 Project Description

The economic importance of mineral production in Canada and the perceived need for greater mining production efficiency were fundamental in conceiving the Pit Slope Research Project.

Briefly, open pit mining involves the excavation of a large amount of waste rock as well as of mineral-bearing ore. On average in Canada, one ton of waste rock is mined for each ton of ore recovered and almost 70% of the minerals mined in Canada are extracted by the open pit method. In many mines the waste rock is removed primarily from the perimeter of the pit. If the total amount of material to be moved can be reduced by cutting steeper slopes, the amount of waste rock involved can be substantially diminished. In Canadian open pit mines, wall slopes are known to vary between 38 and 65 degrees, the average being about 40 degrees. Coates and Dubnie (1971) indicated that an appropriate research and development program could lead to an average increase in slope angles of at least 5 degrees for approximately 75% of open pit production.

A conceptual analysis of the impact of pit slope research - based on the theory of the mining firm - was included in the cost-benefit study. It was concluded that, for conditions prevailing in most metal markets, a decrease in average costs would usually result in an increase of total production from a mine.

Since rock slides rarely occur in the majority of open pits, it was suggested that the existing safety margin is larger than necessary. It was suggested that research work could provide the required scientific data on the behaviour of rock slopes to optimize pit slope design.

It was found that individual mining companies are reluctant to undertake a comprehensive research program on this problem. It was also argued that the benefits from the required development trials, carried out in a pit of advanced life, might come too late to be of benefit to that particular mine. Also, when such trials are being conducted, current operations can be affected. Finally, given the nature of this research project - an investment to provide technical information - a mining company will not invest at the social optimum level, as was discussed in Chapter 1. Hence, Coates and Dubnie concluded that this research project should be initiated either by a government research agency or by some other organization serving the industry.

The CANMET submission to Treasury Board for the Pit Slope Research Project proposed - in keeping with the newly-promulgated "Make or Buy Policy"[1] - to contract-out 75% of the research to outside organizations or individuals. Treasury Board approved the spending of $3.95 million for this purpose; a breakdown of the cost allocation is given in Table 22. Two conditions were attached to the project by Treasury Board: (1) since mining companies were to be the chief recipients of the direct benefits, the private industry was required to contribute 50% of the overall project cost, and (2) an annual evaluation of the previous year's progress should be undertaken using performance measurements prescribed by the selection committee.

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1 See Treasury Board (1973)

TABLE 22: FEDERAL GOVERNMENT ESTIMATES* FOR PIT SLOPE RESEARCH PROJECT

YEAR	BUDGET $,000	MAN-YEARS
1972-73	800	8
1973-74	800	8
1974-75	800	8
1975-76	700	6
1976-77	700	6
1977-78	30	1
1978-79	30	1
1979-80	30	1
1980-81	30	1
1981-82	30	1
TOTAL	3,950	

* Estimated in 1971

The reporting framework seems to have varied from year to year but has always entailed a year-end progress report, drawing on detailed technical reports to present an overall performance picture. Project efforts can be broadly classified, for the first phase, as (1) organizational and procedural; (2) research and development of new techniques; (3) modification of existing techniques to suit the intent of the project; (4) field testing of techniques; and (5) preparation of the Pit Slope Manual.

The total cost of the Pit Slope Research Project to the government has been lower than the values estimated in Table 22. The total cost to government as of March 31, 1977 was $2.82 million. Of this, $1.84 million was spent on outside contracts for R&D. Overall, roughly 30% of the primary research was performed in-house.

The bulk of the primary research, however, together with virtually all the development work, was contracted out. Table 23 summarizes the actual cost of the project in its first phase.

TABLE 23: PIT SLOPE RESEARCH PROJECT - ACTUAL EXPENDITURES

YEAR	GOVERNMENT $,000	INDUSTRY* $,000	TOTAL $,000
1972-73	477.1	272.8	750.0
1973-74	726.2	529.2	1,255.4
1974-75	715.9	394.5	1,110.4
1975-76	675.0	509.8	1,184.8
1976-77**	223.6	49.0	272.6
TOTAL	2,817.8	1,755.4	4,573.2

* Industry generally donated a substantial part of the cost of facilities, labour and equipment

** Estimated March 31, 1977

The actual cost of the project for the government has been 29% lower than the cost estimated in 1971.

6.4.3 The Cost-Benefit Analysis - An Overview

A check-list was used to identify, and later to evaluate, the potential benefits arising from the Pit Slope Research Project. All possible effects were taken into account. The main benefits are as follows.

(1) Direct Benefits accruing to Mining Companies

The relationship of the technological improvements stemming from the project to the resultant economic effects and the nature of the benefits have been concisely stated in the introduction to the Pit Slope Manual (Sage, 1976). Essentially, improving the technology of rock stability by investing an optimal amount in stabilizing procedures permits lower unit excavation cost while maintaining the same or an acceptable level of safety. In the cost-benefit study (Coates and Dubnie, 1971) it was estimated that benefits could possibly total $40 million. No estimate of the uncertainty associated with this value was provided. However, a sensitivity analysis conducted by the author on the possible revenue for a range of increase in slope angles (ranging from 1 degree to 5 degrees) indicates a significant revenue variation. Table 24 shows the effect of increasing the slope angle on revenues:

TABLE 24: RANGE OF DISCOUNTED REVENUES FROM INCREASED PIT SLOPE ANGLES

SLOPE ANGLE INCREASE DEGREE	DISCOUNTED REVENUE RATE OF INTEREST @ 10%	DISCOUNTED REVENUE RATE OF INTEREST @ 15%
	$ mil.	$ mil.
1.0	7.0	6.5
2.5	33.6	16.2
5.0	63.0	30.1

As a result of the research project carried out, an improved pit slope design approach was developed. Thus, the Pit Slope Manual describes procedures to determine the risk of slope instability and also explains how to incorporate the benefits and costs associated with steeper slopes into overall planning. These procedures are based on reliability theory: that is, the analysis of many factors to estimate the probability that a wall or part of a wall will remain stable. The approach developed gives methods of estimating the costs associated with instability. Knowing these costs as well as the mining cost, the planner can determine the costs and benefits of a given wall layout and the associated risks. This information can then be used in making mine investment decisions and in selecting the optimum layout.

(2) Regional Impact

It was indicated in the cost-benefit study that the project would result in increased regional economic activity due to an increase in production, proportional to increase in gross revenue of, possibly, $100 million. Regional activity would also benefit from expansion in the local population. On the other hand, a decrease in competition for scarce resources, such as skilled labour, and a decrease in demand for environmental support, like air and water, were not foreseen if production expanded.

(3) National Results

It was estimated that the national economy would benefit in proportion to both the increased net revenue and increased gross revenue. Expanded foreign exchange earnings were assessed at $75 million. Increased tax receipts were expected to be $35 million. In this respect, it must be stressed that only in so far as foreign-owned companies automatically take additional profits out of the country, are taxes permitted to be counted in a cost-benefit analysis.

(4) Technological Benefits

Another indirect benefit mentioned in the cost-benefit study was the technological spillover - that is, the potential benefits that could be obtained by other industries - due to technical fall-out, for example, highway and dam excavation in rock which are comparable to open pit slopes. No effort was made to quantify these benefits.

Only research costs were considered for the evaluation of the project. The estimated and actual costs are given in Tables 22 and 23 respectively. Although an effort was made to identify and estimate all possible costs resulting from the use of a new pit slope design approach - possibly some $3 million per year - these costs were not emphasized in the final analysis because they were considered to be of an order of magnitude lower than the probable benefits. A few qualifications are necessary in this respect. In any given geological environment, the design of pit slopes involves a trade-off between waste rock removal costs on the one hand and the costs of instability on the other. Assuming a certain low level of risk, deemed to be safe because a low angle is used, increasing the slope angle will increase risk, decreasing safety. This introduces a countervailing cost which must be exceeded by cost-savings in terms of waste removal. However, the risk in the new situation must be reduced to the previous (or alternative design) level by certain precautions (techniques and devices); otherwise the increased risk is a cost that should be accounted for. These risk costs cover not only cleaning up slides and reshaping contours, delays or postponement of mining, and loss of ore (which are factors a mining company is likely to consider when planning), but also the cost to society in terms of injury and loss of life (which the mining company may not allow for in its plans). In any case, loss stemming from increased risk should be entered on the cost side of the cost-benefit calculus.

This dimension of the problem has been duly recognized and analyzed by Kim et al. (1977). The cost aspect of increased slope angle has been emphasized in an example of the application of the new approach where a less steep slope design (38 degrees) is clearly shown as a better alternative to the base case considered (a slope angle of 45 degrees). The probability of achieving any given level of net present value is greater for the less steep slope design than for the base case.

6.4.4 Comments on the Results

The objective of the Pit Slope Research Project was to determine the pit layout that maximizes financial returns and mineral recovery.

As a preliminary evaluation of the research project, a cost-benefit analysis of the R&D effort was conducted. The results of this cost-benefit study are discussed in the light of the project's actual outcome.

Strictly in economic terms, the dominant measurable benefit accrues directly to the operating companies in the form of cost-saving and increased after-tax profit. Redistribution of monetary effects occurs by way of taxes to governments and, in some cases, royalties to governments and/or resource owners.

The cost-benefit analysis emphasized the importance of mining activity in providing new and extended employment opportunities in economically under-developed regions. The analysis rightly noted the nature of the foreign exchange implications for the national economy.

The improved efficiency of the Canadian mining industry is desirable whatever the ownership and market structure of the industry. In the short term, until advancements in pit planning resulting from this research project are put into practice elsewhere, this new capacity will assist the industry's competitive position in international mineral markets. Widespread foreign adoption of such practices, however, while adding to benefits in terms of national prestige for Canada, will eventually reduce this technological advantage.

In this case study, where improved efficiency is achieved through design procedures, there is the attractive feature of efficiency being gained without the employment loss that usually accompanies technological improvements. By enabling more of the nation's resource endowment to be extracted economically, the effect on employment is positive.

Technological considerations also came into play in CANMET's decision to select the most appropriate form of research in effecting a basic industry-wide efficiency drive. The options open to CANMET were to undertake design research or to pursue development of continuous mining systems. Pit slope design was viewed as the appropriate approach since continuous mining systems could not be developed and tested at the production scale because of practical constraints within both CANMET and the industry itself. Ease of field application was, no doubt, a factor favouring stability studies since from this stage it would be a short step to operational application. In fact, consistent with the natural inclinations of scientists, scientific efficiency was likely the first consideration. This application of the cost-benefit analysis approach emphasizes the research aspect of the project rather than the analysis of identifiable economic effects. It stresses the likelihood of project success as opposed to mere hypothetical benefits. Formal cost-benefit analyses can, of course, cope with uncertainty by attaching probability estimates and deriving expected values, but this is not the same approach and will not necessarily lead to the same decision as one placing emphasis on technological success.

The Pit Slope Research Project was not financed under the normal CANMET budget and consequently was not seen to compete with its on-going research projects. In this case, the correct budget perception entailed a choice among competing new projects at the conceptual stage. Of the two technological options suiting the objectives, only the stability technology was deemed feasible, considering practical aspects of mining research. Under these circumstances, there was no need to consider the opportunity cost of alternative expenditures and the decision was reached on the basis of a favourable cost-benefit ratio of a single option.

An analysis of the project's outcome reveals that a probabilistic design approach was developed as a result of the Pit Slope Research

Project. This approach provides the mine operator with guidance in selecting optimum wall angles consistent with his attitude to risk. These procedures permit operators to select appropriate wall angles on the basis of slope stability probability. These concepts are fully explained in a comprehensive engineering manual for open pit planning that has recently been published by CANMET.

The probabilistic design procedure requires more detailed analysis than the conventional factor-of-safety approach. The extra work required is justified by the richness of its results as compared to the results of the factor-of-safety analysis. As an additional benefit of the probabilistic approach, it is mentioned that the effort involved in gathering much of the extra information, such as the cost impact of failure, has the effect of focussing the consequences of a particular design for the decision-maker.

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

This study has described the development of an assessment framework to guide R&D investment decisions in the mineral industry. This framework has been developed considering all aspects of the mineral R&D process. The study consists of seven chapters covering the importance of the research, the R&D process in the mineral industry, previous research, development of a conceptual assessment framework, application to case studies and a discussion of their results.

The review of the economic characteristics of the innovation process reveals that basic research constitutes that portion of the R&D spectrum which has the strongest theoretical justification for government support. The question of criteria for the allocation of resources, especially public resources, to applied research has received substantially less attention than that of basic scientific research. With regard to mineral R&D, it is found that government support is essential in developing those technologies needed for the future development of the domestic mineral industry but not undertaken by the private sector because of lack of incentive.

The economic outcome of a mineral research project is greatly influenced by broad economic, social and political forces interacting with the innovation process in the mineral industry. These factors determine technological progress and the rate of adoption of a new technology by the industry and, consequently, the expected value of an R&D project and its probability of success. The specific characteristics of the mineral research process were considered in order to develop some analytical methods for project evaluation and selection. Essentially, (1) mineral research is generally process or operations oriented; (2) the industry output is a commodity with almost no product differentiation; (3) given the high R&D cost, laboratory conditions are either of the small batch type or closed circuit recycling, information provided in this way being highly uncertain.

The project selection decision is concerned with the allocation of organizational resources, such as money, skills and facilities, to a set of R&D projects. The review of the literature regarding techniques for the evaluation and selection of R&D projects shows the existence of a large number of proposed models. It is found, however, that little use is made of these models, partly due to the fact that most of them are not able to describe the reality of the innovation process or the sequential nature of the decision process and they do not take into account multiple criteria. The development of a suitable assessment framework was then undertaken with consideration being given to the following performance criteria: realism, flexibility, use and cost.

The decision process in innovation is considered to be sequential from the idea stage to the production stage. A logical consequence of process sequentiality is the recognition of milestones that represent the completion of distinct R&D phases. Conceptual changes are noted during the course of the project and represent a continuous improvement in the quality of the data available during various project stages.

In a multi-project mineral R&D organization, the selection of new projects has to be accommodated to the planning of on-going projects since they compete for the same expert staff, laboratory equipment and other facilities and resources. The approach developed in this study selects projects which will achieve the best total benefit, within the limits set by the resources available. Two R&D project evaluation and selection techniques are recommended for allocating resources to mineral research projects in a large organization - the cost-effectiveness analysis approach and the cost-benefit analysis approach.

The cost-benefit analysis approach has a stronger theoretical foundation for resource allocation than the cost-effectiveness analysis technique. However, in practice, the difficulties in obtaining reliable information for evaluating a set of research projects at different stages of the innovation process prevent its application to the entire set of projects. Thus, a cost-effectiveness analysis approach, based on additive scoring models and employing the Delphi method for polling experts' opinion, is recommended for assessing the different research projects.

On the other hand, the cost-benefit analysis technique provides a rational framework for decision-making in the case of projects in applied research which require a long time commitment and sizable quantity of resources for completion. The use of different economic models, depending on project stage, has been proposed here. These models must suit the specific characteristics of a particular stage. The rigor of the evaluation technique should increase with the increase in magnitude of resources demanded.

CANMET - Canada's largest mining research organization - is selected as a specific case study to test and investigate the suitability of these approaches to large mineral research organizations. The characteristics of CANMET's Mineral Research Program are examined for the purpose of defining the parameters of the cost-effectiveness and cost-benefit approaches.

In Chapter 5, the cost-effectiveness approach is applied to CANMET's mineral research program. Two scoring models, supported by a Delphi method of polling expert opinion, are employed. The first model represents the first attempt to use a systematic and rational model for the evaluation of R&D projects in CANMET. The second scoring model departs from the first, utilizing basically the same concepts but possessing a simpler structure.

The cost-benefit analysis approach is illustrated by its application to two case studies outlined in Chapter 6 - the New Brunswick Complex Base Metal Ores Research Project and the Pit Slope Research Project. The assessment of a new process for treating the complex base metal ores of New Brunswick is carried out when the bench scale research stage for three prospective process alternatives has concluded. The risk analysis model, using a Monte Carlo simulation technique, is applied for dealing with the evaluation of this advanced stage project. The application of the cost-benefit approach to the Pit Slope Research Project - an actual research project conducted by CANMET - is described and a critique of the application is presented.

7.2 Conclusions and Recommendations

Expenditure on R&D is an investment for which a return is expected, as with any other business investment. In a large R&D organization, potential and existing projects compete for the limited resources available. The whole range of its activities, therefore, needs to be coordinated and planned to ensure that resources are used efficiently to obtain the best possible total benefits. The problem of resource allocation for mineral R&D is complicated by the inherent uncertainty of R&D, the multiple purpose for which it is undertaken, the numerous social and organizational contexts within which it is conducted and the differing values placed upon it by various groups in society. This study has described the development of an assessment framework for guiding mineral R&D investment decisions for a large research organization. This assessment framework makes use of a cost-effectiveness analysis approach and of a cost-benefit analysis approach for the allocation of resources to mineral research projects. These approaches incorporate the most recent developments in economic evaluation and decision-making techniques. Furthermore, several aspects, which have been omitted in previous studies but which are, nevertheless, important considerations in mineral R&D investment decisions, are included in the assessment framework proposed in this study. The case studies analysed in Chapters 4, 5 and 6 demonstrate the practical applicability of the investment optimization framework. It is hoped that this study may provide guidelines for R&D investment in the mineral industry at large.

Several important conclusions are drawn from the case study applications.

(1) The cost-effectiveness analysis approach presents clearly defined advantages over the cost-benefit analysis approach when investment decisions are made regarding a set of R&D projects of different research natures and at various research stages. On the other hand, the cost-benefit analysis approach is recommended as a useful tool for decision-makers for analysing those R&D projects that require a long time commitment and a sizable amount of resources for completion.

(2) The cost-effectiveness analysis approach is based on additive scoring models, supported by a Delphi method of polling expert opinions. Additive scoring models do not produce a large range of scores for project effectiveness. This narrow range of values results in biases when projects are expressed in terms of effectiveness-cost ratio and cost is considered as an absolute value. The case study results presented in Chapter 5 show this effect. Thus, a critical factor of these scoring models is the choice of appropriate scales to express input estimates. Further investigation of the effect of using different scales over project scores and ranking is recommended.

(3) Application of the marginal effectiveness-cost ratio criteria within a budgeting context provides a more appropriate tool than simple effectiveness-cost ratio criteria in deciding which projects are the first to receive additional funding or to be cut back under budget constraints. The marginal effectiveness-cost ratio criteria reduces the bias towards small projects which is found in the rankings based on simple effectiveness-cost ratio criteria. The marginal effectiveness-cost ratio criteria favours only those projects that are more sensitive to budget change. Further research is

recommended to examine the validity of the assumption that only the probability of technical success of a project is affected by a change in the level of project funding.

(4) The experience of using the cost-effectiveness analysis approach is limited to three years and the cost-benefit analysis approach has been used on two occasions. However, the assessment framework developed is conceptually attractive and flexible enough to be easily adopted in operating environments different from those considered in this study. More actual case studies must be analysed to investigate the suitability of these approaches for different environments, namely commercial and non-profit R&D organizations.

(5) In order to be of any value, the formulation of a model must be acceptable to the research staff and management as a realistic representation of their organization's situation and activities. Since a model needs to be tailored to the particular needs of the organization, it is advisable to start with a relatively simple model to gain experience. As the need arises, the complexity of the model can be increased. Acceptance of the model is made easier when it is gradually introduced, first as a trial on a few projects and later extended to the whole set of projects. For instance, the cost-effectiveness analysis approach was applied to the research projects of CANMET's Utilization activity only after the approach was applied to the research projects of the Mining and Processing activities.

(6) A major benefit to CANMET, arising from the use of the models developed, has been that it has made managers more aware of the information they should have in order to make good decisions. As a result, R&D managers consider R&D projects more carefully and from a broader perspective. The use of these models allows managers to identify more clearly those projects which are well worth investing time and effort in, and those projects which are clearly not worth

serious consideration. Furthermore, it enables managers to terminate unsuccessful projects at the earliest time justified. However, like other quantitative management techniques, the use of these models constitutes an aid to management decision processes and is not a substitute for them. The use of these models helps researchers more readily to accept closure of a project by making the argument for project termination less subjective. In addition, the use of these models makes scientists more aware of the effectiveness of their projects in meeting the organization's objectives; consequently, scientists submit more elaborated justifications for their R&D project proposals.

(7) The validity of the results obtained from the models developed and their usefulness in management decision-making depend, to a great extent, on the cooperation of the researchers and managers who particpate in the project assessment. Comprehension on the part of project assessment participants concerning the characteristics and limitations of the model employed is another critical factor in this respect.

(8) The models employed contain elements such as estimates of probability of success, time to completion of R&D, research project costs and production costs, amongst others. The accuracy of these input estimates cannot be predicted initially and it may take many years to judge their accuracy. Undoubtedly, the involvement of researchers and managers in project evaluation has helped the learning process, and the accuracy of model parameters will improve. It is recommended in this study that further research be conducted into the question of the accuracy of input estimates necessary to remove inconsistency of results. More importantly, this research should provide guidance to researchers and managers in order to make forecast estimates more accurate.

STATEMENT OF ORIGINALITY AND CONTRIBUTION TO KNOWLEDGE

The following aspects of the present work are considered to be contributions to knowledge:

1. A systematic study of the technical, economic, social, ecological and political factors that have influenced the innovation process in the mineral industry was presented. To the author's knowledge, no study of these factors in relation to the mineral R&D process has previously been made. The analysis of these factors contributes to the advancement of the technology assessment of mineral R&D activities, since these factors determine technological progress and the rate of adoption of a new technology by the industry. It has also been shown that the analysis of these factors provides a frame of reference for the development of realistic decision-making models for mineral R&D activities.

2. An assessment framework for guiding mineral R&D investment decisions for a large research organization was developed. This assessment framework makes use of a cost-effectiveness analysis approach and a cost-benefit analysis approach for the allocation of resources to mineral research projects. These approaches incorporate the most recent developments in economic evaluation and decision-making techniques. Furthermore, several aspects, which have been omitted in previous studies but which are, nevertheless, important considerations in mineral R&D investment decisions, are included in the assessment framework proposed in this study.

3. Additive scoring models, employing the Delphi method for polling experts' opinions, were developed for a cost-effectiveness analysis of research projects in a large mineral R&D organization. The application of these scoring models to CANMET's research projects

has shown that the cost-effectiveness analysis approach presents clearly defined advantages over the cost-benefit analysis when investment decisions are made regarding a set of R&D projects of different research natures and at various research stages.

4. The applicability of a cost-benefit analysis approach for the evaluation and selection of large mineral R&D projects of applied research nature was investigated. This approach makes use of differential economic models according to the research projects' stage. The application of this approach to case studies has shown that the information obtained with the proposed models provides a useful tool to decision-makers for analysing those R&D projects that require a long time commitment and a sizable amount of resources for completion.

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APPENDICES

APPENDIX A

RESULTS OF THE FIRST SCORING MODEL

TABLE A-1: CONSENSUS DEVELOPMENT BY THE DELPHI METHOD. RANKING OF THE FIRST MODEL'S OBJECTIVES

OBJECTIVES	First Round			Second Round		
	Mean Weight (%)	Standard Deviation	Ranking Order	Mean Weight (%)	Standard Deviation	Ranking Order
(1) Social-Labour Considerations						
1.1 Identify and encourage viable mineral development in areas with insufficient employment opportunities	3.42	0.90	17	4.20	1.11	14
1.2 Promote community stability by extending viable life of mineral operations	4.25	1.10	13	5.47	1.45	8
1.3 Meet consumer demands in the provision of mineral-based products	3.49	0.91	16	4.17	1.14	15
1.4 Promote comfortable, satisfying and healthy community life	3.13	0.95	18	-	-	-
1.5 Ensure occupational health, safety and comfort	4.69	1.33	9	7.68	2.15	1
1.6 Promote better regional distribution of income	2.35	0.67	20	2.90	0.87	18
1.7 Obtain a greater share of mineral resource income for Social Programs	1.82	0.56	21	1.64	0.50	19
(2) Ecology Considerations						
2.1 Harmonize mineral-based development with multiple and sequential land use	4.26	1.13	12	4.62	1.22	12
2.2 Minimize environmental degradation	7.08	1.80	3	7.64	1.98	3
2.3 Improve water and soil quality	4.82	1.25	8	5.14	1.36	10
2.4 Recover, reuse or recycle waste materials	6.54	1.68	5	6.67	1.76	5
(3) Economic Considerations						
3.1 Foster industrial productivity	6.19	1.61	6	-	-	-
3.2 Promote further domestic processing	7.84	2.01	1	7.64	2.03	2
3.3 Promote the development of secondary industries based on utilization of mineral products	6.75	1.74	4	6.47	1.71	7
3.4 Develop more efficient methods of winning materials from minerals	7.54	1.95	2	7.36	1.95	4
(4) Resource Supply and Sovereignty Considerations						
4.1 Strive for greater self-sufficiency	-	-	-	-	-	-
4.2 Promote and encourage the replacement of imports, including equipment, supplies and services	4.04	1.10	14	4.74	1.30	11
4.3 Undertake development planning in Northern regions and territories	3.63	0.94	15	3.95	1.08	16
4.4 Substitute abundant for scarce materials: identify and develop key sub-marginal deposits	4.45	1.14	11	4.58	1.21	13
4.5 Promote optimum recovery and use from mining, processing and utilization systems	6.17	1.56	7	6.54	1.76	6
4.6 Strengthen bargaining position re imports	3.01	0.79	19	3.32	0.92	17
4.7 Improve the inventory of physical, technical and economic characteristics of earth resources available to Canada	4.53	1.17	10	5.27	1.39	9

TABLE A-2: COST EFFECTIVENESS RESULTS FOR M.R.P.'S PROJECT ELEMENTS: PROCESSING ACTIVITY

P-1 Project - Complex Pb-Zn-Cu-Fe-S Ores

	PROJECT ELEMENT	EFFECTIVENESS	E/C RATIO
1.	Leach Liquor Treatment: Bacterial Leaching	61.4	14.6
2.	Surface and Electrochemical Studies of Sulphides in Relation to Flotation	201.0	13.4
3.	Computer Programs for Analytical Methods in the Chemistry Laboratory	91.2	13.0
4.	Ion Exchange Processes: Bacterial Leaching of Cu-Zn Sulphide Ores	119.5	10.2
5.	Percolation Leaching of Chalcocite-Bornite Ore with Ammoniacal Solutions	114.7	10.1
6.	Recrystallization of Fine-Grained Sulphide Ore by Chemical Transport	79.6	10.0
7.	Mineralogy and Microscope Analysis	30.3	8.0
8.	Percolation Leaching of Chalcopyrite Ore with Ammoniacal Solutions	114.7	6.6
9.	Anodic Dissolution of Lead Sulphides	93.2	6.0
10.	Dissolution of Chalcopyrite in Ferric Ion Media	114.7	6.0
11.	Zinc Electrolysis	100.5	6.0
12.	Ore Characterization	88.4	5.1
13.	ZnS-PbS-FeS Phase Studies	93.1	4.7
14.	Electrochemical Dissolution of Copper Sulphides	93.2	4.7
	- - - - - - - - MINING + PROCESSING ACTIVITIES AVERAGE - - - - -		4.1
15.	Percolation Leaching of Pyrite Zn-Pb-Cu Ores with Ferric Ion Media	114.7	3.6
	- - - - - - - - - - - PROCESSING ACTIVITY AVERAGE - - - - - - - - -		3.5
16.	Crystal Structure Studies of Members of the Stannite Family	86.5	3.3
17.	Crystallography of the Stannite Family	86.5	3.1
18.	The Role of Chloride Ion and Organic Extractant in the Electrowinning of Co	42.4	2.8

TABLE A-2 continued - P-1 Project continued

	PROJECT ELEMENT	EFFECTIVENESS	E/C RATIO
19.	Computer Programs for Kinetic Studies in the Metallurgical Chemistry Section	33.1	2.5
20.	The Mineralogy, Stoichimetry and Stability Relation of the Stannite Family	88.4	2.4
21.	Dissolution of Sphalerite in Ferric Chloride Solutions	114.7	2.1
22.	X-Ray Fluorescence on Line Analysis of Pb-Zn Ore Fractions	58.1	1.8
23.	Bacterial Leaching	61.4	1.8
24.	Ore Analysis by Optical Emission Spectroscopy	58.1	1.7
25.	Quantimet Analysis of Base Metal Ores	30.3	0.6
	TOTAL P-1 PROJECT	2,169.5	4.0

P-2 Project - Ferrous Extractive Metallurgy

1.	Steelmaking by Shaft Electric Reduction Furnace	84.8	20.1
2.	Iron and Steelmaking	84.8	15.1
3.	Ferro-Alloy Manufacture	56.5	13.5
4.	Electric Furnace Technology: State-of-the-Art Review	63.3	11.3
5.	Treatment of Leach Residue	59.8	10.7
	- - - - - - - MINING + PROCESSING ACTIVITIES AVERAGE - - - - -		4.1
6.	Cupola Smelting of PRIO	94.9	4.0
7.	Beneficiation of PRIO	317.4	3.6
	- - - - - - - - - - - PROCESSING ACTIVITY AVERAGE - - - - - - - - -		3.5
8.	Eastern Titaniferous Magnetite Project: Roast, Leach and Separation	241.9	2.9
9.	Electric Smelting of PRIO	136.7	0.9
10.	Mineralogy of PRIO and Concentrate	29.6	0.6
11.	Effect of Zn on Iron Ore Pellets in the Blast Furnace	35.0	0.4
	TOTAL P-2 PROJECT	1,204.7	2.4

TABLE A-2 continued

P-3 Project - Inorganic Non-Metallic Materials

	PROJECT ELEMENT	EFFECTIVENESS	E/C RATIO
1.	Design of an Efficient Kiln for Processing Lightweight Aggregates	114.4	19.1
2.	Degradation of High-Alumina Cements	75.6	16.8
3.	Use of Waste for Railroad Ballast	91.0	13.0
4.	Recovery of Useful Materials from Plant Wastes	92.1	10.8
5.	Research in Asbestos	92.1	10.2
6.	Commodities	69.9	10.0
7.	Evaluation of Biodegradable Flotation Reagents	131.1	9.4
8.	Thermal Properties of Materials for Heat Storage	125.4	8.1
9.	Development of Beta-Alumina	159.4	8.0
10.	Electronic Mineral Sorting Techniques	30.3	6.7
11.	Development of a Dry-Pressed Building Brick	47.7	6.5
12.	Development of Translucent Alumina	159.4	6.4
13.	Comparative Grindability of Non-Metallics	55.2	5.5
14.	Thermal Properties of Concrete	97.1	5.1
15.	Glass as a Bonding Agent in Ceramics	83.2	5.0
16.	In-Place Evaluation of Concrete	75.6	4.5
	MINING + PROCESSING ACTIVITIES AVERAGE		4.1
17.	Use of Waste as Aggregate in Concrete and Asphalt	217.2	4.0
18.	Bloating Properties of Lightweight Aggregates	75.6	3.7
19.	Reduction of Energy Required for Glass Production	84.1	3.5
	PROCESSING ACTIVITY AVERAGE		3.5
20.	Development of an Autoclave Building Brick	47.7	3.4
21.	Development of High K Microwave Dielectrics	114.4	3.4
22.	Comparative Flotability of Non-Metallics	55.2	3.3
23.	Development of New Types of Concrete (No Fines and Sulphur Infiltrated)	123.3	2.8

TABLE A-2 continued - P-3 Project continued

	PROJECT ELEMENT	EFFECTIVENESS	E/C RATIO
24.	Waste Source Reports	86.4	2.8
25.	Development of a High Grade Zirconia Electrolyte	159.4	1.9
26.	Behaviour of Concrete at High and Low Temperatures	75.6	1.5
27.	Evaluation of Crushed Sand and Aggregate	75.6	0.9
28.	Processing Clay and Shales	38.7	0.4
29.	Development of Mineral Beneficiation Techniques (for Carbonates)	28.6	0.2
	TOTAL P-3 PROJECT	2,681.5	3.1

P-5 Project - Precious and Platinum Group Metals

1.	Characterization of Precious-Metal-Bearing Minerals Associated with Ni-Cu Ores	189.8	6.7
2.	Development of Economical Methods for Controlling Concentration of Cyanide and Cyanite Complex in Effluents from Gold	422.3	4.7
	- - - - - - - - MINING + PROCESSING ACTIVITIES AVERAGE - - - - - -		4.1
	- - - - - - - - - - - PROCESSING ACTIVITY AVERAGE - - - - - - - - -		3.5
3.	The Mineralogy of the Platinum-Group Elements	101.4	2.7
	TOTAL P-5 PROJECT	713.6	4.6

P-6 Project - Security of Supply

1.	Melt-Quench	395.5	15.8
2.	Clay-Acid Leach	395.1	15.8
3.	Investigation of Some Aspects of the Physical Chemistry of the Lime-Soda Process for Extracting Alumina from Anorthosite	56.2	11.2
	- - - - - - - - MINING + PROCESSING ACTIVITIES AVERAGE - - - - - -		4.1
	- - - - - - - - - - - PROCESSING ACTIVITY AVERAGE - - - - - - - - -		3.5
	TOTAL P-6 PROJECT	846.7	15.4

TABLE A-2 continued

Research Agreements Related to the Processing Activity

	PROJECT ELEMENT	EFFECTIVENESS	E/C RATIO
1.	Recovery of Magnesium Sulphate from Saline Lakes. Saskatchewan Research Council	240.1	24.0
2.	Development of Solvent Extraction System for Cobalt and Nickel in Acid Media. York University	183.7	20.4
3.	Electrochemical Studies on Mineral Flotation. University of Ottawa	142.9	14.3
4.	Computer Calculation of Phase Equilibrium Conditions for Ternary Systems Containing Oxygen, Sulphur and C. Ecole Polytechnique	126.2	14.0
5.	Reclamation of Water from Mill Tailings. University of British Columbia	78.3	13.0
6.	The Effect of Trace Elements as Lattice-Bound Impurities on the Flotation of Common Base Metal Sulphides. New Brunswick Research and Productivity Council	79.4	11.3
7.	Digital Simulation of the Brenda Concentrator. University of British Columbia	88.2	11.2
8.	Caractérisation des minérais de fer au moyen d'un réacteur à contre-courant. Ecole Polytechnique	73.3	9.8
9.	A Study of the Ferric Species Present in Leaching Solutions by Mossbauer Spectroscopy. Carleton University	83.2	9.2
10.	Ore Mineralogy of the Anaconda-Caribou Primary Ore. New Brunswick Research and Productivity Council	29.6	4.2
	- - - - - - - MINING + PROCESSING ACTIVITIES AVERAGE - - - - -		4.1
	- - - - - - - - - - - PROCESSING ACTIVITY AVERAGE - - - - - - - - -		3.5
11.	Environmental Effects in Comminution and Rock Drilling. University of B.C.	26.6	2.7
12.	The Effect of Grinding Media on Selective Flotation of Pb-Cu-Fe-S Ores. Lakefield Research of Canada Ltd.	55.2	0.5
	TOTAL RESEARCH AGREEMENTS RELATED TO THE PROCESSING ACTIVITY	1,206.6	5.7
	TOTAL RESEARCH AGREEMENTS RELATED TO THE MINING AND PROCESSING ACTIVITIES	2,236.8	8.3

TABLE A-2 continued

MINING ACTIVITY

PROJECT ELEMENT	EFFECTIVENESS	E/C RATIO
Open Pit Mining Project		
1. Embankments	177.1	27.3
2. Blasting	330.0	22.5
3. Groundwater	251.9	9.1
4. Monitoring	373.6	6.5
---------- MINING ACTIVITY AVERAGE ----------		5.0
------- MINING + PROCESSING ACTIVITIES AVERAGE -----		4.1
5. Material Testing	289.8	3.0
6. Structural Geology	305.6	3.0
7. Environmental Planning	352.0	2.2
8. Design	210.9	1.8
9. Support	141.7	1.6
TOTAL OPEN PIT MINING PROJECT	2,432.5	3.6
Waste Disposal Project		
1. Water Treatment	474.9	12.3
2. Revegetation	361.0	12.2
3. Tailing Treatment	361.0	10.2
4. Biological Weathering	445.5	6.2
---------- MINING ACTIVITY AVERAGE ----------		5.0
------- MINING + PROCESSING ACTIVITIES AVERAGE -----		4.1
TOTAL WASTE DISPOSAL PROJECT	1,642.4	9.4
Underground Mining Methods Project		
1. Electro-Osmosis	197.5	17.0
---------- MINING ACTIVITY AVERAGE ----------		5.0
2. Cut and Fill	353.7	4.5
------- MINING + PROCESSING ACTIVITIES AVERAGE -----		4.1
3. Open Pit to Underground	173.6	2.1
TOTAL U/G MINING METHODS PROJECT	724.8	4.2

TABLE A-2 continued - Mining Activity continued

PROJECT ELEMENT	EFFECTIVENESS	E/C RATIO
Mining Equipment Project		
1. Communications	211.2	16.9
------------ MINING ACTIVITY AVERAGE ----------		5.0
------- MINING + PROCESSING ACTIVITIES AVERAGE -----		4.1
2. Raise Borer	59.6	3.0
TOTAL MINING EQUIPMENT PROJECT	497.1	4.7
Environment Project		
1. Radiation	609.0	15.2
2. Noise	445.7	8.6
3. Continuous Monitoring	507.0	8.0
4. Dust	502.0	7.6
5. Infrared Quartz	106.8	5.9
------------ MINING ACTIVITY AVERAGE ----------		5.0
6. Explosives Fumes	183.9	4.8
------- MINING + PROCESSING ACTIVITIES AVERAGE -----		4.1
7. Diesel Emissions	194.8	4.0
8. Explosives Hazards	163.0	0.9
TOTAL ENVIRONMENT PROJECT	2,712.0	5.2
Marine Mining Project		
1. Marine Mining	171.5	28.6

TABLE A-2 continued - Mining Activity continued

PROJECT ELEMENT	EFFECTIVENESS	E/C RATIO
Research Agreements Related to the Mining Activity		
1. The Capacity of Mineral Production and Transportation Systems. Ecole Polytechnique	122.7	33.2
2. Underground Controlled-Pulse Acoustic Measurement. University of Saskatchewan	200.9	28.7
3. Mine Production Standard without Judgement Factors. Queen's University	140.1	26.4
4. Application of Photogrammetric Terrain Digitizating Systems in Surface Mining. Queen's University	186.6	20.7
5. Determination of Stresses in Potash Mines for Application of Mining Designs. Saskatchewan Research Council	199.9	20.0
6. Laser Rock Breakage	120.4	12.0
7. Influence of the Water Table on Open Pit Mines and its Control. Laval University	59.6	6.0
- - - - - - - - - - - - MINING ACTIVITY AVERAGE - - - - - - - - - -		5.0
- - - - - - - MINING + PROCESSING ACTIVITIES AVERAGE - - - - -		4.1
TOTAL RESEARCH AGREEMENTS RELEVANT TO THE MINING ACTIVITY	1,030.2	18.7
TOTAL RESEARCH AGREEMENTS RELATED TO THE MINING AND PROCESSING ACTIVITIES	2,236.8	8.3

APPENDIX B

RESULTS OF THE SECOND SCORING MODEL

TABLE B-1: EVALUATION OF A RESEARCH PROPOSAL

Please refer to the accompanying list and definition of projects.

1) Identification of the project -

Activity:
Sub-Activity:
Sub/Sub-Activity
Project:
Project Annual Cost:
Fiscal Year:

2) Assessment of the project significance to MRP objectives. Using the scale shown below, assess the significance of the project to each of the MRP objectives listed.

NO.	MRP OBJECTIVES	PROJECT SIGNIFICANCE
1	Develop technology to reduce all human diseases and environmental health hazards related to mineral industry activities, including non-occupational diseases	
2	Develop technology to improve safety from injury in the workplace	
3	Develop technology to improve worker comfort	
4	Develop technology to conduct mineral industry activities and dispose of wastes and effluents in a manner which minimizes conflict with other resources and land uses, including recreational uses	
5	Develop technology to lower operating costs and raise levels of recovery in mining	
6	Develop technology to enable efficient or more efficient processing of minerals for both conventional and unconventional natural resources	
7	Develop technology to improve efficiency in metallurgical extraction	
8	Develop technology to improve efficiency in semi-fabrication	
9	Develop technology to improve secondary recovery from wastes and scrap	
10	Develop technology to improve situations where specific opportunities for further domestic up-grading of minerals and mineral products are seen, or can be foreseen, to be limited by deficiencies in lack of technology	
11	Apply technological research to the development of improved mineral-based products and processes, especially where these replace the use of scarce resources	
12	Undertake research to find new uses specifically for mineral and metal wastes	

TABLE B-1 continued

Scale for Evaluating the Significance of a Project to MRP Objectives

Disregarding technical success and economic feasibility, this research	
- promises to best advance knowledge in pursuit of this objective	1.00
- promises to substantially and directly advance knowledge in pursuit of this objective	0.70
- promises to directly, but to a lesser extent, advance knowledge in pursuit of this objective	0.45
- promises to substantially, but indirectly, advance knowledge in pursuit of this objective	0.25
- may, to a lesser extent, indirectly advance knowledge in pursuit of this objective	0.10
- may not significantly advance knowledge in pursuit of this objective	0.00

3) Estimation of the probability of technical and, if applicable, economic success

	N/A	High (0.9)	(0.7)	Medium (0.6)	(0.4)	Low (0.2)
Probability of technical success	☐	☐	☐	☐	☐	☐
Probability of economic success	☐	☐	☐	☐	☐	☐

4) Sensitivity of the probability of technical success to change in funding

	Incremental change with an increase in funding of			Decremental change with a decrease in funding of		
	50%	30%	10%	10%	30%	50%
Change in the probability of technical success	☐	☐	☐	☐	☐	☐

5) Self-rating of the participant's expertise and knowledge of the scientific and/or technological field of the project

Fully Coincident (1.0)	Directly Related (0.8)	Indirectly Related (0.4)	General Knowledge (0.2)
☐	☐	☐	☐

TABLE B-2: SENSITIVITY ANALYSIS: MARGINAL EFFECTIVENESS/COST RATIOS FOR VARIOUS LEVELS OF CHANGE IN FUNDING FOR THE MINING ACTIVITY

P#	EFFECTIVENESS	EFFEC./COST	+50% COST	+30% COST	+10% COST	-10% COST	-30% COST	-50% COST
1	11.3	21.4	1.9	.9	0.0	0.[illegible]	21.1	15.5
2	6.3	5.6	2.6	1.6	3.5	7.0	12.2	9.9
3	5.0	32.4	3.9	3.3	0.0	0.0	55.4	35.2
4	6.0	7.6	3.4	3.3	1.6	1.6	18.9	14.3
5	2.6	46.4	0.0	0.0	0.0	980.5	490.3	294.2
6	11.6	22.9	6.2	5.2	0.0	0.0	44.1	33.6
7	11.6	27.6	12.8	14.2	0.0	0.0	62.2	50.7
8	3.2	6.9	.1	0.0	0.0	.9	8.4	6.7
9	3.9	29.5	1.9	1.4	0.0	8.3	57.4	37.2
10	9.1	1.1	.1	.1	0.0	.4	1.5	1.4
11	10.2	11.0	2.8	4.2	4.7	9.5	17.9	14.6
12	10.3	17.6	3.3	4.9	6.3	6.3	24.7	28.4
13	7.3	15.6	6.4	3.8	6.7	6.7	24.2	19.7
14	9.5	9.2	2.8	3.0	3.8	3.8	10.7	11.2
15	8.4	13.0	4.1	3.5	5.3	5.3	14.8	16.7
16	12.8	5.8	2.0	2.5	3.4	3.4	5.9	7.2

TABLE B-3: **SENSITIVITY ANALYSIS: MARGINAL EFFECTIVENESS/COST RATIOS FOR VARIOUS LEVELS OF CHANGE IN FUNDING FOR THE PROCESSING ACTIVITY**

P#	EFFECTIVENESS	EFFEC./COST	+50% COST	+30% COST	+10% COST	-10% COST	-30% COST	-50% COST
17	23.2	2.3	.6	.8	.5	3.3	3.6	3.4
18	22.0	1.3	.6	.5	.3	.4	1.1	1.1
19	9.7	13.9	2.4	1.5	0.0	11.9	19.8	15.9
20	10.2	44.5	7.9	4.8	2.3	41.3	54.3	49.1
21	21.8	2.0	.2	.3	0.0	.2	.6	.9
22	11.7	3.6	.9	1.4	1.3	1.4	3.3	3.4
23	9.7	42.0	12.1	0.0	0.0	29.0	56.7	55.7
24	11.5	16.4	5.3	1.0	3.1	2.9	5.8	11.7
25	12.5	4.9	.7	.2	0.0	1.8	2.7	8.1
26	7.2	7.8	3.0	3.1	4.6	4.6	9.9	11.3
27	5.3	5.6	3.0	2.4	0.0	7.1	8.2	8.8
28	8.2	17.5	.5	0.0	0.0	.7	.7	15.5
29	13.1	11.4	.4	0.0	0.0	2.8	2.8	14.6
30	9.9	10.7	3.1	3.8	3.8	5.5	8.2	8.0
31	6.5	28.1	10.5	15.1	19.4	10.3	26.9	25.2

TABLE B-4: SENSITIVITY ANALYSIS: MARGINAL EFFECTIVENESS/COST RATIOS FOR VARIOUS LEVELS OF CHANGE IN FUNDING FOR THE UTILIZATION ACTIVITY

P#	EFFECTIVENESS	EFFEC./COST	+50% COST	+30% COST	+10% COST	-10% COST	-30% COST	-50% COST
32	5.6	3.3	1.2	1.4	0.0	0.0	5.7	5.8
33	14.3	4.5	1.6	2.0	0.0	.8	7.4	8.5
34	11.4	7.3	4.2	3.8	0.0	.9	8.4	11.7
35	8.6	11.5	4.4	4.8	4.8	0.0	16.1	22.2
36	5.5	15.1	10.8	8.3	.5	0.0	24.2	27.2
37	13.1	2.8	1.5	1.2	0.0	0.0	4.4	5.4
38	9.2	3.8	1.0	1.3	.1	.1	5.3	7.1
39	12.9	21.[illegible]	5.5	8.0	5.4	5.4	36.6	30.8
40	6.9	19.6	25.2	20.1	0.0	5.5	35.6	42.8
41	13.3	1.8	1.0	.6	0.0	.4	2.4	2.6
42	9.5	3.5	.8	.6	0.0	1.6	2.7	5.0
43	6.6	2.8	1.2	.9	.3	1.5	3.0	4.8
44	7.9	7.4	3.6	1.7	.6	4.4	12.5	15.1
45	9.3	13.1	4.3	2.8	0.0	3.9	11.6	25.6
46	13.8	5.9	1.7	.6	0.0	1.5	3.5	8.8
47	16.6	4.2	1.4	.6	0.0	0.0	1.6	6.9

TABLE B-5: RANKING OF RESEARCH PROJECTS ACCORDING TO DIFFERENT CRITERIA - UTILIZATION ACTIVITY - THE ECONOMIC EFFECT OF THE PROJECTS IS CONSIDERED

EFFECTIVENESS			EFFECT./COST RATIO			MARGINAL E/C FOR +50% COST			MARGINAL E/C FOR +30% COST			MARGINAL E/C FOR +10% COST			MARGINAL E/C FOR -10% COST			MARGINAL E/C FOR -30% COST			MARGINAL E/C FOR -50% COST		
P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC
47	1	.6	39	1	.7	40	1	.6	40	1	.6	39	1	.8	40	1	.6	39	1	.8	40	1	.6
33	2	.5	40	2	.5	36	2	.6	36	2	.6	35	2	.5	39	2	.8	40	2	.6	39	2	.8
46	3	.7	36	3	.6	39	3	.8	39	3	.8	44	3	.7	44	3	.7	36	3	.6	36	3	.6
41	4	.8	45	4	.6	35	4	.5	35	4	.5	36	4	.6	45	4	.7	35	4	.5	45	4	.7
37	5	.4	35	5	.5	45	5	.7	34	5	.6	43	5	.6	42	5	.9	44	5	.7	35	5	.5
39	6	.7	44	6	.6	34	6	.6	45	6	.7	38	6	.5	46	6	.7	45	6	.7	44	6	.7
34	7	.6	34	7	.6	44	7	.7	33	7	.6	32	7	.5	43	7	.6	34	7	.6	34	7	.6
42	8	.8	46	8	.7	46	8	.7	44	8	.7	33	7	.6	34	8	.6	33	8	.6	46	8	.7
45	9	.6	33	9	.5	33	9	.6	32	9	.5	34	7	.6	33	9	.6	32	9	.5	33	9	.6
38	10	.4	47	10	.6	37	10	.4	38	10	.5	37	7	.4	41	10	.9	38	10	.5	38	10	.5
35	11	.5	38	11	.4	47	11	.7	37	11	.4	40	7	.6	38	11	.5	37	11	.4	47	11	.7
44	12	.6	42	12	.8	43	12	.6	43	12	.6	41	7	.9	32	12	.5	46	12	.7	32	12	.5
40	13	.5	32	13	.5	32	13	.5	47	13	.7	42	7	.9	35	12	.5	43	13	.6	37	13	.4
43	14	.6	37	14	.4	41	14	.9	41	14	.9	45	7	.7	36	12	.6	42	14	.9	42	14	.9
32	15	.5	43	15	.6	38	15	.5	46	15	.7	46	7	.7	37	12	.4	41	15	.9	43	15	.6
36	16	.6	41	16	.8	42	16	.9	42	16	.9	47	7	.7	47	12	.7	47	16	.7	41	16	.9

TABLE B-6: RANKING OF RESEARCH PROJECTS ACCORDING TO DIFFERENT CRITERIA - UTILIZATION ACTIVITY - ONLY SCIENTIFIC AND TECHNICAL MERITS ARE CONSIDERED

EFFECTIVENESS			EFFECT./COST RATIO			MARGINAL E/C FOR +50% COST			MARGINAL E/C FOR +30% COST			MARGINAL E/C FOR +10% COST			MARGINAL E/C FOR -10% COST			MARGINAL E/C FOR -30% COST			MARGINAL E/C FOR -50% COST		
P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SPC	P#	RO	SRC	P#	RO	SRC
37	1	.4	40	1	.5	40	1	.4	40	1	.4	35	1	.6	40	1	.4	40	1	.4	40	1	.4
47	2	.6	36	2	.6	36	2	.5	36	2	.5	39	2	.7	44	2	.7	36	2	.5	36	2	.5
41	3	.8	39	3	.7	39	3	.7	39	3	.7	36	3	.5	39	3	.7	39	3	.7	39	3	.7
34	4	.6	45	4	.6	35	4	.6	35	4	.6	44	4	.7	45	4	.7	35	4	.6	45	4	.7
33	5	.5	35	5	.5	34	5	.6	34	5	.6	43	5	.6	43	5	.6	44	5	.7	35	5	.6
46	6	.7	34	6	.6	45	6	.7	45	6	.7	38	6	.5	46	6	.7	45	6	.7	44	6	.7
42	7	.8	44	7	.6	44	7	.7	32	7	.5	32	7	.5	42	7	.9	34	7	.6	34	7	.6
40	8	.5	46	8	.7	37	8	.4	33	8	.6	33	7	.6	34	8	.6	32	8	.5	32	8	.5
38	9	.4	32	9	.3	32	9	.5	44	9	.7	34	7	.6	33	9	.6	33	9	.6	38	9	.5
39	10	.7	38	10	.4	43	10	.6	38	10	.5	37	7	.4	41	10	.9	38	10	.5	45	10	.7
35	11	.5	42	11	.8	33	11	.6	37	11	.4	40	7	.4	38	11	.5	37	11	.4	33	11	.6
45	12	.6	33	12	.5	46	12	.7	43	12	.6	41	7	.9	32	12	.5	43	12	.5	42	12	.9
36	13	.6	47	13	.6	47	13	.6	42	13	.9	42	7	.9	35	12	.6	46	13	.7	47	13	.6
32	14	.5	43	14	.6	38	14	.5	47	14	.6	45	7	.7	36	12	.5	42	14	.9	43	14	.6
43	15	.6	37	15	.4	41	15	.9	46	15	.7	46	7	.7	37	12	.4	41	15	.9	37	15	.4
44	16	.6	41	16	.8	42	16	.9	41	16	.9	47	7	.6	47	12	.6	47	16	.6	41	16	.9

TABLE B-7: RANKING OF RESEARCH PROJECTS ACCORDING TO DIFFERENT CRITERIA - UTILIZATION ACTIVITY RESULTS WITHOUT CONSIDERING SELF-RATING COEFFICIENTS

EFFECTIVENESS			EFFECT./COST RATIO			MARGINAL E/C FOR +50% COST			MARGINAL E/C FOP +30% COST			MARGINAL E/C FOR +10% COST			MARGINAL E/C FOR -10% COST			MARGINAL E/C FOR -30% COST			MARGINAL E/C FOP -50% COST		
P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	PO	SRC	P#	PO	SRC	P#	PO	SRC	P#	PO	SRC
46	1	1.0	39	1	1.0	40	1	1.0	40	1	1.0	35	1	1.0	40	1	1.0	40	1	1.0	40	1	1.0
47	2	1.0	40	2	1.0	36	2	1.0	36	2	1.0	39	2	1.0	39	2	1.0	39	2	1.0	39	2	1.0
41	3	1.0	36	3	1.0	39	3	1.0	39	3	1.0	43	3	1.0	44	3	1.0	36	3	1.0	45	3	1.0
33	4	1.0	45	4	1.0	35	4	1.0	35	4	1.0	44	4	1.0	43	4	1.0	35	4	1.0	36	4	1.0
34	5	1.0	35	5	1.0	45	5	1.0	34	5	1.0	36	5	1.0	45	5	1.0	44	5	1.0	35	5	1.0
39	6	1.0	34	6	1.0	34	6	1.0	45	6	1.0	38	6	1.0	33	6	1.0	45	6	1.0	44	6	1.0
37	7	1.0	44	7	1.0	44	7	1.0	44	7	1.0	32	7	1.0	42	7	1.0	34	7	1.0	34	7	1.0
45	8	1.0	46	8	1.0	46	8	1.0	33	8	1.0	33	7	1.0	34	8	1.0	33	8	1.0	46	8	1.0
42	9	1.0	33	9	1.0	33	9	1.0	32	9	1.0	34	7	1.0	46	9	1.0	32	9	1.0	33	9	1.0
35	10	1.0	47	10	1.0	47	10	1.0	43	10	1.0	37	7	1.0	41	10	1.0	43	10	1.0	47	10	1.0
44	11	1.0	42	11	1.0	43	11	1.0	37	11	1.0	40	7	1.0	38	11	1.0	46	11	1.0	43	11	1.0
43	12	1.0	32	12	1.0	37	12	1.0	47	12	1.0	41	7	1.0	32	12	1.0	38	12	1.0	42	12	1.0
38	13	1.0	43	13	1.0	32	13	1.0	46	13	1.0	42	7	1.0	35	12	1.0	37	13	1.0	32	13	1.0
40	14	1.0	38	14	1.0	41	14	1.0	38	14	1.0	45	7	1.0	36	12	1.0	42	14	1.0	38	14	1.0
36	15	1.0	37	15	1.0	42	15	1.0	42	15	1.0	46	7	1.0	37	12	1.0	41	15	1.0	37	15	1.0
32	16	1.0	41	16	1.0	38	16	1.0	41	16	1.0	47	7	1.0	47	12	1.0	47	16	1.0	41	16	1.0

TABLE B-8: RANKING OF RESEARCH PROJECTS ACCORDING TO DIFFERENT CRITERIA

- ONLY SCIENTIFIC AND TECHNICAL MERITS ARE CONSIDERED

EFFECTIVENESS			EFFECT./COST RATIO			MARGINAL E/C FOR +50% COST			MARGINAL E/C FOR +30% COST			MARGINAL E/C FOR +10% COST			MARGINAL E/C FOR -10% COST			MARGINAL E/C FOR -30% COST			MARGINAL E/C FOR -50% COST		
P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC	P#	RO	SRC
21	1	.5	23	1	.5	40	1	.4	40	1	.4	31	1	.6	5	1	.3	5	1	.3	5	1	.3
18	2	.7	20	2	.5	23	2	.7	31	2	.6	13	2	.6	20	2	.6	6	2	.8	23	2	.7
17	3	.7	5	3	.3	13	3	.6	13	3	.6	24	3	.3	23	3	.7	7	3	.9	9	3	.6
22	4	.6	31	4	.5	36	4	.5	36	4	.5	12	4	.6	24	4	.8	9	4	.6	40	4	.4
23	5	.6	40	5	.4	31	5	.5	7	5	.3	30	5	.8	31	5	.6	23	5	.7	7	5	.8
37	6	.4	9	6	.5	20	6	.5	12	6	.6	25	6	.5	15	6	.5	20	6	.6	6	6	.8
24	7	.8	3	7	.8	7	7	.8	20	7	.6	35	7	.6	19	7	.7	40	7	.4	20	7	.6
47	8	.6	7	8	.8	24	8	.8	39	8	.7	39	8	.7	11	8	.5	13	8	.6	36	8	.5
30	9	.6	36	9	.5	6	9	.8	30	9	.6	11	9	.5	9	9	.6	3	9	.8	13	9	.6
16	10	.5	6	10	.8	28	10	.7	24	10	.8	15	10	.5	13	10	.6	31	10	.6	31	10	.6
20	11	.5	24	11	.9	12	11	.6	26	11	.5	20	11	.6	12	11	.6	36	11	.5	3	11	.8
41	12	.8	1	12	.8	30	12	.8	35	12	.6	2	12	.8	40	12	.4	39	12	.7	12	12	.6
34	13	.5	28	13	.6	14	13	.5	6	13	.8	14	13	.5	28	13	.7	12	13	.6	39	13	.7
33	14	.5	39	14	.7	39	14	.7	14	14	.5	14	14	.5	27	14	.5	19	14	.7	43	14	.7
46	15	.7	19	15	.7	35	15	.6	34	15	.6	4	15	.7	2	15	.8	15	15	.5	[illegible]	15	.7
42	16	.8	13	16	.6	34	16	.5	11	16	.5	22	16	.7	30	16	.8	4	16	.7	35	16	.6
40	17	.4	12	17	.5	45	17	.7	4	17	.7	36	17	.5	44	17	.7	11	17	.5	15	17	.5
19	18	.7	33	18	.8	3	18	.8	16	18	.5	44	18	.7	26	18	.5	1	18	.5	19	18	.7
6	19	.8	15	19	.5	4	19	.7	3	19	.8	43	19	.6	39	19	.7	35	19	.6	26	19	.8
38	20	.6	45	20	.5	44	20	.7	15	20	.5	17	20	.7	45	20	.7	2	20	.8	4	20	.7
39	21	.7	35	21	.5	15	21	.5	27	21	.5	18	21	.7	29	21	.7	14	21	.5	11	21	.5
29	22	.6	11	22	.5	27	22	.5	45	22	.7	38	22	.5	14	22	.5	44	22	.7	44	22	.7
7	23	.9	14	23	.5	26	23	.5	9	23	.6	1	23	.8	16	23	.5	25	23	.5	1	23	.8
1	24	.8	29	24	.6	9	24	.6	32	24	.5	3	23	.8	17	24	.7	45	24	.7	29	24	.7
25	25	.5	26	25	.5	19	25	.7	22	25	.7	5	23	.3	4	25	.7	8	25	.6	14	25	.8
14	26	.5	4	26	.7	16	26	.5	2	26	.9	6	23	.8	22	26	.7	30	26	.8	34	26	.6
11	27	.5	34	27	.5	2	27	.8	33	27	.6	7	23	.8	43	27	.6	27	27	.5	26	27	.5
36	28	.5	44	28	.6	11	28	.5	44	28	.7	8	23	.6	8	28	.6	34	28	.6	30	28	.8
28	29	.6	9	29	.6	1	29	.8	19	29	.7	9	23	.6	25	29	.5	28	29	.7	2	29	.6
45	30	.6	27	30	.4	37	30	.4	38	30	.5	10	23	.5	46	30	.7	32	30	.5	27	30	.5
12	31	.6	16	31	.5	8	31	.5	8	31	.5	19	23	.7	42	31	.9	24	31	.8	8	31	.5
31	32	.5	2	32	.8	32	32	.5	1	32	.8	21	23	.5	34	32	.6	16	32	.5	16	32	.5
15	33	.5	22	33	.6	22	33	.7	37	33	.4	23	23	.7	33	33	.6	33	33	.6	32	33	.5
35	34	.5	46	34	.7	43	34	.6	43	34	.5	25	23	.5	10	34	.6	38	34	.5	38	34	.5
32	35	.5	32	35	.5	33	35	.6	42	35	.9	27	23	.5	18	35	.7	37	35	.4	46	35	.7
26	36	.5	38	36	.4	46	36	.7	17	36	.7	28	23	.7	41	36	.9	22	36	.7	33	36	.6
10	37	.5	42	37	.8	47	37	.6	47	37	.6	29	23	.7	21	37	.5	29	37	.7	25	37	.5
43	38	.6	25	38	.5	38	38	.5	46	38	.7	32	23	.5	38	38	.5	43	38	.6	42	38	.9
44	39	.6	33	39	.5	29	39	.7	41	39	.9	33	23	.6	1	39	.8	46	39	.7	47	39	.6
13	40	.6	47	40	.6	41	40	.9	18	40	.7	34	23	.6	3	39	.8	17	40	.7	22	40	.7
2	41	.8	43	41	.6	42	41	.9	21	41	.5	37	23	.4	6	39	.8	42	41	.9	43	41	.6
4	42	.7	37	42	.4	25	42	.5	25	42	.5	40	23	.4	7	39	.8	41	42	.9	37	42	.4
27	43	.6	17	43	.7	18	43	.7	10	43	.6	41	23	.9	32	39	.5	25	43	.5	17	43	.7
3	44	.8	21	44	.5	17	44	.7	5	44	.3	42	23	.9	35	39	.6	47	44	.6	41	44	.9
9	45	.6	41	45	.8	21	45	.5	23	44	.7	45	23	.7	36	39	.5	10	45	.6	10	45	.6
8	46	.6	18	46	.7	10	46	.6	28	44	.7	46	23	.7	37	39	.4	18	46	.7	18	46	.7
5	47	.3	10	47	.6	5	47	.3	29	44	.7	47	23	.6	47	39	.6	21	47	.5	21	47	.5

P#: Project Number   RO: Ranking Order   SRC: Self-Rating Coefficient

APPENDIX C

SOME DETAILS OF THE COMPLEX BASE METAL ORES PROCESSES

C.1 The Dry-Way Chlorination Process

In this process, a zinc-lead-copper bulk concentrate is dried and contacted with chlorine to convert the mineral sulphides to soluble chlorides. The chlorinated calcine is then contacted with oxygen to oxidize and remove iron. The oxidized calcine is leached in a brine solution to dissolve the soluble chlorides. The next step, crystallization, is to recover lead. This is followed by the solvent extraction and electro-winning steps to recover zinc and copper.

TABLE C-1: ESTIMATED INSTALLED CAPITAL COSTS: DRY-WAY CHLORINATION PROCESS*

ITEM	REACTOR RETENTION TIME		
	30 min. $ mil.	60 min. $ mil.	180 min. $ mil.
Drying Section	1.61	1.61	1.61
Chlorination Section	13.39	18.62	34.86
Sulphur Recovery Section	4.38	4.38	4.38
First Stage Oxidation Section	13.39	18.62	34.86
Second Stage Oxidation Section	5.54	5.54	5.54
Brine Leaching Section	1.40	1.40	1.40
Chlorine Recycle Section	1.50	1.50	1.50
Oxygen Plant	5.43	5.43	5.43
Steam Plant	1.33	1.33	1.33
Electrolysis, Melting and Casting and Auxiliary Facilities (Zn Plant)**	36.53	36.53	36.53
Copper Sx-Electro-winning Plant**	3.27	3.27	3.27
Lead/Silver Recovery Plant	4.10	4.10	4.10
Leach-Purification Cadmium Recovery**	17.40	17.40	17.40
Plant Facilities	4.36	5.84	9.09
Plant Utilities	5.23	7.01	10.91
Total Capital Costs	114.45	132.55	172.18

* based on estimates provided by Kelly (1978)

** based on estimates provided by Research and Productivity Council (1978)

TABLE C-2: ESTIMATED ANNUAL OPERATING COSTS: DRY-WAY CHLORINATION PROCESS*

ITEM	REACTOR RETENTION TIME		
	30 min. $ mil.	60 min. $ mil.	180 min. $ mil.
Raw Materials	3.83	3.83	3.83
Utilities	3.05	3.07	3.17
Direct Labour	4.98	4.98	4.98
Plant Maintenance	2.33	2.90	4.63
Payroll Overhead and Operating Supplies	2.69	3.15	3.36
Taxes and Insurance	1.19	1.43	2.22
Total Operating Costs	18.07	19.36	22.19

* sources: Kelly (1978) and Research and Productivity Council (1978)

C.2 The Sherritt Pressure Leaching Process

The proposed processing technology is a combination of Sherritt's acid pressure leach process and conventional purification and electrowinning technology.

The Sherritt process comprises the direct acid leaching of the concentrate in an autoclave under an oxygen overpressure and is followed by a counter current decantation wash of the leach residues. A second stage counter current pressure leaching of the residues is necessary to enhance copper extraction and to make the recovery of that metal economically feasible. The acid zinc pressure leach solution from the first stage leach undergoes a two-stage process to remove iron. This is followed by conventional solution purification and cadmium recovery. Zinc metal is extracted as jumbo cathodes by electrolysis. Melting and casting of zinc into slabs or ingots produces the final product.

The leach residue from the second stage pressure leach, which consists of lead and iron sulphates, elemental sulphur and gangue, can be further processed to recover by-products. Elemental sulphur and pyrite are removed from the washed leach residue which is then further up-graded to produce a silver/lead sulphate concentrate.

TABLE C-3: CAPITAL COST ESTIMATES: SHERRITT PRESSURE LEACHING PROCESS*

ITEM	BULK CONCENTRATE $ mil.	UPGRADED TAILINGS $ mil.
Leach and Purification Plants	33.91	34.12
Electro-winning Plant	31.09	31.09
Melting and Casting Plant	2.82	2.82
Auxiliary and Utility Plants	16.38	16.38
Sitework and Non-Process Buildings	8.97	8.97
Indirects	22.85	22.85
Feasibility Study and Start-up Costs	2.02	2.02
Total Capital Costs	118.04	118.25

* based on estimates provided by Sherritt Gordon Mines Ltd. (1978) and Research Productivity Council - RPC (1978)

TABLE C-4: OPERATING COST ESTIMATES SHERRITT PRESSURE LEACHING PROCESS*

ITEM	BULK CONCENTRATE $ mil.	UPGRADED TAILINGS $ mil.
Labour	7.24	7.24
Operating Supplies	5.60	4.80
Maintenance Materials	1.33	1.33
Utilities	10.81	10.76
Taxes and Insurance	0.95	0.95
Total Operating Costs	25.93	25.08

* based on estimates provided by Sherritt Gordon Mines Ltd. (1978) and RPC (1978)

C.3 The RPC Sulphation Roast Process

The RPC Sulphation Roast Process is similar to conventional zinc dead roast-leach-electrowinning practices. Differences occur in the roasting conditions, methods of separating zinc from iron present in the feed and the method of copper recovery.

The RPC Sulphation Roast Process consists of a fluidized bed sulphation roast, followed by a two-stage leach of roaster calcines. The first stage is a dilute sulphuric acid leach. The second stage consists of a hot strong acid leach. Purification includes solvent extraction, extraction-electrowinning of copper, iron oxidation and percipitation, and cadmium recovery. Zinc is then recovered by electrolysis.

TABLE C-5: CAPITAL COST ESTIMATES: DEAD ROAST AND SULPHATION ROAST PROCESSES*

ITEM	DEAD ROAST	SULPHATION ROAST	
		BULK CONCENTRATES	TAILINGS REFLOATS
	$ mil.	$ mil.	$ mil.
Zinc Plant	106.48	122.28	125.42
Copper Sx-Electrowinning Plant	-	3.27	3.27
Lead/Silver Recovery Plant	-	5.31	2.88
Indirect Costs	29.63	33.10	33.79
Total Capital Costs	136.11	163.96	165.36

* Source: Research Productivity Council (1978)

TABLE C-6: OPERATING COST ESTIMATES: DEAD ROAST AND SULPHATION ROAST PROCESSES*

ITEM	DEAD ROAST $ mil.	SULPHATION ROAST BULK CONCENTRATES $ mil.	SULPHATION ROAST TAILINGS REFLOATS $ mil.
Labour	7.50	8.46	8.46
Power	7.27	7.48	7.47
Reagents	1.31	3.57	3.49
Operating and Maintenance Supplies	2.94	3.23	3.21
Maintenance Capital Expenditures	0.80	1.00	1.00
Fuel	1.07	1.23	1.15
Taxes and Insurance	0.86	1.07	1.08
Total Operating Costs	21.76	26.04	25.86

*. Source: Research Productivity Council (1978)