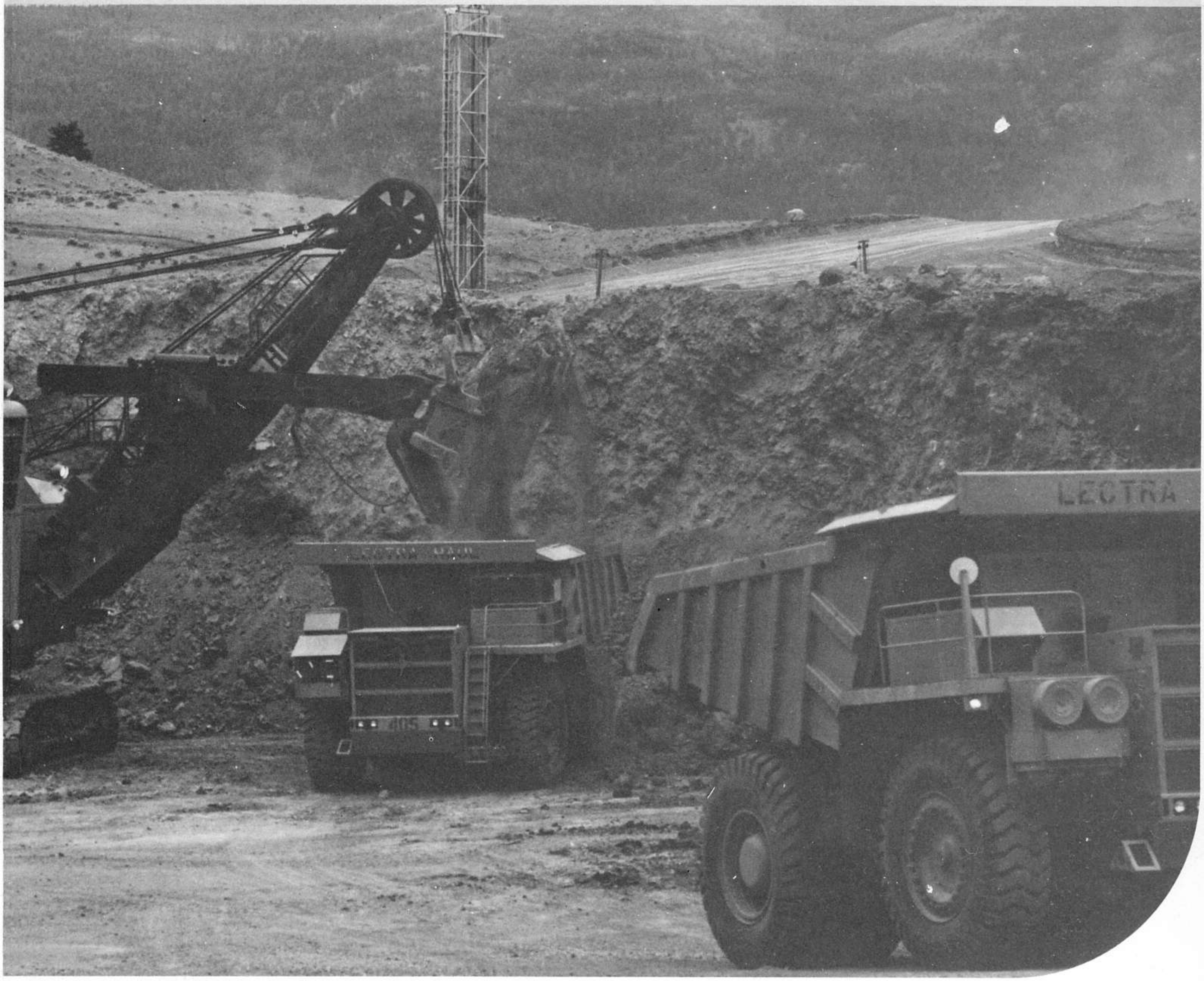
MINSIM

A Metal Mine Simulation Model
Stage 1 Report



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Province of British Columbia

Ministry of Energy, Mines and Petroleum Resources

ECONOMICS AND PLANNING DIVISION

MINSIM

A Metal Mine Simulation Model

STAGE I REPORT

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Economics & Planning Division
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EXECUTIVE SUMMARY

MINSIM is being developed as a tool to assist the B.C. Ministry of Energy, Mines and Petroleum Resources in testing and evaluating the effects of various public policy measures and the influence of external factors on the financial health of the B.C. mining industry. It may also be used to aid in cost-benefit analysis of public expenditures in mining, commodity and market supply studies, and analysis of the B.C. mining investment climate.

The project is organized into four stages:

STAGE I - Documentation and analysis of existing techniques.

STAGE II - Selection of model input, output, and target variables, and development of key model equations.

STAGE III - Development of the simulation model and computer programming of the final model form.

STAGE IV - Testing and validation of the model, and operation in specific applications.

This paper summarizes the research completed in Stage I as outlined below:

1) literature search of existing mine models and modelling theory;

2) study and definition of mine valuation concepts and simulation techniques;

3) description, documentation, and analysis of existing available mine models. Four mine models were chosen for detailed study using flowcharting and construction of input variable taxonomies. Reports presenting technical details of the models, model viewpoint and scope, a general outline of model operations, description of model features, options, and output were written for each of these models. Their results are summarized in this paper. In addition, other models not suitable for detailed analysis are reviewed briefly;

4) identification of public policy questions and their significance in mine modelling;

5) a brief study of mine financing instruments and their effects on mine valuation.

The above information was evaluated in terms of MINSIM purpose and objectives to derive a framework for MINSIM development. The main features of this framework are as follows:

1) Viewpoint

The model will assume a private valuation perspective, with capability for calculating mine valuation on a 100% - equity basis, as well as valuation under the actual financial structure. This will provide a value for the mine independent of financing, a measure of the effects of existing financing, and values of the mine to each financial participant. Government rents will also be calculated.

2) Simulation Approach

Sensitivity anlaysis and comparative statics will be employed in MINSIM. Whether the approach used will be probabilistic or deterministic is undecided.

3) Scope

The planning/valuation process can be classified into four interdependent steps:

I Ore Reserve Calculation

II Pit Design and Location

III Production Scheduling

IV Financial Analysis

Data detail and availability will probably not permit modelling of the first two steps. Furthermore, accurate representation of steps I and II for any one mine would probably destroy the general applicability of the model for other B.C. mines. However, the model will be structured in such a way that it will be able to accept data in these areas for the purpose of accurately modelling production schedules. In this way, modules that may be developed in the future for performing steps I and II on a mine-specific basis can be used to generate input for MINSIM without reducing the models' flexibility and general applicability.

4) Operational Detail

The following divisions of model operation are identified: production scheduling; cost estimation; revenue calculation; balance sheet accounting; mine management operating decisions; public policy modules; and output measures. Some interrelationships between these divisions are specified, and options and features available for use in each area (as uncovered in the models studied) are reviewed.

This report also develops guidelines for Stage II research. These guidelines represent a procedure for evaluating the options, features, and approaches available in the various areas of mine modelling and model operational detail. Many of these options have been identified and described in Stage I research. The approach in

Stage II will be to solicit feedback and suggestions from interested and knowledgeable parties in the mining industry, the public sector, and the academic community in the major areas of mine modelling methodology, mine operations, mine financing, costing, and public policy. Research on data detail, accuracy, and availability in these areas will form the framework for evaluation of the modelling options.

Objectives of Stage II research include identification of key model variables and equations and the development of a preliminary MINSIM flowchart.

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ACKNOWLEDGEMENTS

Many organizations and individuals provided information, comments, and suggestions that proved very useful in the course of Stage I research. In particular, the help of Simon Handelsman of B.C. Hydro (formerly of RTZ), Dr. Y.C. Kim of the University of Arizona, Michael Power of Noranda Mines, Dr. Richard L. Sanford of the University of Wisconsin - Platteville, and Pat Cash and James K. Wright of Wright Engineers is gratefully acknowledged.
The project is under the overall direction of Frank C. Basham, Assistant Director, Economics and Planning Direction.

PREFACE

MINSIM is the name given to an applied research project within the Ministry of Energy, Mines and Petroleum Resources which seeks to evolve a computer-assisted metal mine simulation model. The model will be used as an analytical tool to evaluate the impacts of public policy initiatives or other exogenous influences on financial performance for specific or hypothetical mining situations.

A major reason for publishing the Stage I Report is to stimulate commentary and discussion on our approach and findings in order to benefit subsequent stages of the work. To this end, we would encourage direct contact with the research team. It is, of course, necessary to remind readers that any views expressed or policy options identified in this document are those of the research team and not necessarily those of the Ministry or Government of British Columbia.

Frank C. Basham
Assistant Director,
Economics and Planning Division
November, 1978

I. INTRODUCTION

1.1 The Need for a Model of B.C. Mines

The past two decades have seen sweeping changes in the B.C. mining industry. Bethlehem's success in mining low grade porphyry copper ores in the Highland Valley area using low unit cost open-pit mining methods ushered in a new era in the industry. Several porphyry copper and stockwork molybdenum deposits were discovered, developed, and placed into operation in the favourable economic and political atmosphere of the 1960's and early 70's. Since then, many factors have combined to drastically change this environment. Metal price declines (especially in copper), changing tax structures and increased effective tax rates, political uncertainties, rapidly escalating capital and operating costs, labour disruptions, and rising social concern regarding the exploitation of mineral resources and its effect on the environment have resulted in a decline in the health of the industry in B.C. This is evidenced by mine closures, cut-backs in production, reduced profitability, and postponements of and reductions in mineral exploration and development programs.

The increased prosperity and dynamic growth of the mining industry in the 60's and early 70's attracted the attention of both Provincial and Federal governments, reflecting increasing public awareness of the role of the industry in the provincial economy. This resulted in many changes in a hitherto very stable and generally favourable legislative and tax environment. Unfortunately, these changes were followed by a severe decline in the economic environment, and the magnitude of effects of legislative changes on the viability of the mining industry are still not fully understood or agreed upon. Subsequent legislative changes and revisions which have attempted to help restore the health of the industry have further complicated analysis of the effects of the political and economic factors affecting the industry in recent years.

It should be clear from the above discussion that some means of analysing the effects of the various policy and economic factors affecting the mining industry is necessary. A useful tool favoured for such analysis by several mining companies and government agencies is the simulation model. However, there does not presently exist a model for B.C. mines which is applicable to the various B.C. mining operations and which possesses the desired flexibility and detail necessary for effective public policy and financial analysis.

MINSIM, a simulation model for B.C. metal mines to be developed by the B.C. Ministry of Energy, Mines and Petroleum Resources, is designed to fulfill this need.

The objectives of such a model, as outlined in the MINSIM Terms of Reference, are as follows:

> "The project will research and develop a computerized metal mine simulation model to be used as an aid in resource management planning and policy studies for the Ministry of Energy, Mines and Petroleum Resources. Thus, the major purpose of the research is to develop an in-house analytic tool to assist the Ministry in quantitative evaluation of policies affecting the mineral sector in British Columbia.

The model would have the ability to simulate and measure the financial position of a mining operation and specifically, the sensitivity of viability of an operation to changes in both controllable and non-controllable input parameters. Such simulation exercises would provide insights into the operations in question and would indicate the financial effect of current or proposed policy. The model would eventually be developed to analyse the financial implications of future expansions as well as new mining projects although initial research emphasis would be on simulation of existing operations."

The following are possible specific end-uses of a simulation model eminating from the research project:

1. Evaluation of alternative taxation systems;
2. Evaluation and analysis of mine operational characteristics;
3. Analysis of the effects of fluctuation and changes in the non-controllable factors affecting mining (eg. metal prices, capital and operating cost inflation);
4. Comparison of costs of various mining and processing methods and their influence on the economics of mineral deposits;
5. Evaluation of mineral deposits for analysis of supply of specific commodities;
6. Assessment of the economic and financial viability of a mine property;
7. Economic analysis of mine closures or production cutbacks;

8. Input to social benefit-cost (SBC) analyses of public infrastructure investment for new mining projects, or to SBC analysis of policy initiatives;
9. Analysis of the effects of various factors on mine life, ore reserves, cut-off grade and production rates;
10. Comparison of the B.C. mining investment climate with other similar mining regions.

It should be emphasized that such a model is not designed to evaluate the effects of such subjective questions as investor preference, the effects of political uncertainty on mining investment, the desirability of regional development programs, or the assessment of an area's mineral potential, except where it may serve as a data base or information source.

1.2 Organization of the MINSIM Project

MINSIM will be developed in four stages:

STAGE I - Research and documentation of existing mine models, and modelling approaches and techniques.

STAGE II - Selection of model input, output, and target or instrumental variables, and development of key model equations.

STAGE III - Development of the simulation model and computer programming of the final model form.

STAGE IV - Testing of the model, and operation in specific applications.

The present report is a summary of Stage I research, and will outline a preliminary framework for the MINSIM model, as well as present recommendations on refining and expanding the terms of reference for subsequent stages of the project.

Section II outlines the information sources and methods of analysis employed in Stage I research. The results of the research and descriptions of modelling theory, approaches, and mine models. and modelling techniques are summarized in Section III. Section IV presents a framework for the development of the simulation model, with comments and suggestions on useful modelling approaches, techniques, and options. Section V presents recommendations for the further development of the model.

II. APPROACH IN STAGE I RESEARCH

2.1 Sources of Information

Information on metal mine models, modelling theory, and related topics was gathered from several sources. A body of literature was first compiled from known sources and preliminary library searches. Personal contacts in universities, the mining industry, and consulting services (see Appendix A) provided valuable assistance and suggestions regarding mine modelling approaches and model features, information on literature available in the public domain, and access to some private and, in some cases, proprietary material.

A computerized literature search under various relevant search keywords and phrases was conducted at U.B.C. using the INSPEC data base. Further computer searches on this and other bibliographic data bases* were performed at the B.C. Legislative Library under a wide variety of search terms.

A "Directory of Digital Computer Programs for the Mining Industry" has been compiled by Dr. Richard L. Sanford**, but is not yet available. This directory will include a list and summary of both public-domain as well as private and proprietary programs. An abbreviated bibliography of public-domain literature related to the MINSIM project was compiled from this directory for the Ministry of Energy, Mines and Petroleum Resources by Sanford.

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* Other data bases searched were INSMEC, NTIS, COMPENDEX, MANAGEMENT INDEX, ACCOUNTING, and INFORM.

**Sanford, Richard L.; Terry L. Myers; and Jon F. Stiehr: "Directory of Digital Computer Programs for the Mining Industry", AIME Pre-print 78-AR-55 AIME, Salt Lake City, Utah, 1978.

A complete summary of the reviewed models and literature pertaining directly or periferally to the MINSIM project is supplied in Appendix B at the end of this report. Due to the proprietary and private nature of much of the research in mine modelling, and because this field is fairly new and rapidly expanding, this bibliography is by no means exhaustive. In particular, constraints of time and proprietary right did not permit the acquisition and investigation of mine models developed and used by several companies. Some effort will be directed in Stage II towards establishing contact with appropriate industry personnel in order to discuss the characteristics and capabilities of these models.

With the above-noted exceptions, the literature reviewed comprises a major and representative segment of the work done in mine modelling.

2.2 Investigations of Mines Modelling Literature

In the course of literature search and investigation, material on a wide range of topics relevant to the development of MINSIM was collected and analysed. The literature studied can be grouped under the following main topics:

1. Mine valuation theory.
2. Simulation theory and main approaches.
3. Mine models suitable for detailed analysis.
4. Other "whole system" mine models.
5. Models of segments of mine operations.
6. Public policy factors: their effects on and treatment

in mine evaluation and modelling.

7. Mine financing and its significance in mine modelling.

These topics are dealt with in detail in Section III.

2.3 Criteria and Techniques Used in Model Analysis

In choosing models for detailed analysis, the following factors were considered:

1. The scope of the model. Only those models which simulated the entire mining operation (as opposed to, for example, truck haul simulators or operating cost "partial" models) were considered for detailed investigation.

2. Availability of the program source code and detail of documentation. Although several source codes were proprietary, excellent descriptions permitted a fairly detailed analysis to be performed.

3. Detail and sophistication in modelling actual mine operation.

4. Applicability to the B.C. open-pit metal mining situation. Factors such as provision for B.C. and Canadian tax systems, type of metal and ore deposit modelled, method of mining, and geographic applicability of the models to the B.C. environment were considered in choosing models which would be the most applicable and informative in terms of MINSIM development.

5. Financial capabilities and validity of measures and concepts employed.

6. Model viewpoint. Models evaluating a mine from both private and social viewpoints were studied in order to identify differences in the approaches and assess the advantages of including a social valuation module in MINSIM.

The computer models chosen for detailed study are:

1. The open pit coal mining model developed for Kemmerer Coal Company of Wyoming by Kim and Dixon[13].

2. The Helliwell-Bradley model of B.C. open pit copper mines[17,18,19].

3. ERDA's Cash Flow Analysis Model for U.S. surface coal mining operations[22].

4. J.K. Wright's "Computer Valuation Model for Mining Companies"[24].

It will be noted that two of the four above models are coal mine models. One may wonder at their inclusion in a study of metal mine modelling. Firstly, the methodologies employed in these models are also applicable to open pit metal mine modelling, especially with respect to truck-haul production scheduling, cost estimation, and cash flow analysis. Secondly, information on these models was obtainable, whereas many metal mine models used by industry are strictly proprietary.

Several techniques were employed in the analysis of these models. Where program source codes were available, detailed flowcharts were constructed to facilitate understanding of the flows and logic employed in the models. These flowcharts were, in some cases, condensed for ease of exposition and brevity. Where necessary, assistance in model and source code interpretation was readily available from model "authors". Input variable taxonomies were compiled in cases for which this was not conveniently or adequately summarized in model documentation and descriptions. Reports have been written on each model[16,21,23,25]. These reports summarize technical details of the model (length, computer language used, access, etc.), its purpose and objectives, code ownership, simulation approach used, model scope, viewpoint (private vs. social), a general outline of model operation, description of special model features, and description and analysis of output content and format. Comments and suggestions are made regarding applicability of model segments, approaches, or features in the development of MINSIM. Section 3.3 of this report summarizes these findings.

Many mine and financial models not suitable for detailed study were investigated using some of the techniques of analysis mentioned above. Other "whole system" mine valuation models (i.e. those which model the entire mining operation) are reviewed in Section 3.4. Models of certain aspects and segments of mining operations such as ore reserve calculation, pit design and location, production scheduling, and cost estimation are covered in Section 3.5. Emphasis here is on programs and mine model segments which are of particular interest to MINSIM, although some outline of less important areas is provided as an aid to formulation of a general mine modelling framework.

III. SUMMARY OF LITERATURE STUDIES

3.1 Mine Valuation Theory

The first step in developing a mine model is to establish a valid theoretical basis upon which mines can be evaluated. The concept of discounting the value of future cash flows* back to present values is now well accepted. There are, however, several methods by which this may be done.

A traditional valuation measure used in the mining industry is the Hoskold formula[5,8]:

$$V_p = \frac{E}{\left(\frac{f}{(1 + f)^n - 1}\right) + r}$$

where: r = risky rate of return on invested capital; f = riskless (safe) rate of return on reinvested capital redemption; E = annual earnings, assumed constant over mine life; n = life of project; and V_p = present value of future mine earnings.

The Hoskold formula attempts to recognize the mineral deposit as a wasting asset by setting up a sinking fund which accumulates over the life of the mine. These funds collect interest at a "risk-free" rate, and can be used to purchase another mine when the first is exhausted. The ore deposits thereby approximate a perpetuity. There are several problems with this approach. Firstly, the formula uses

*Note the distinction between cash flows and profits. Since profit is an accounting term and is subject to non-cash accounting items such as depreciation, its real value to the owner is not clearly defined. It is therefore not valid to discount profits.

two different rates of return, a risky rate of return earned on capital invested in the mine, and a lower risk-free rate earned on funds generated by the mine and placed in the sinking fund. In fact, mines do not set up sinking funds to replace depleted ore deposits. Funds earned from the mine are reinvested in mining (or other investments), and thus earn returns at a risky rate. The Hoskold formula assumes that funds obtained from the mine earn interest at the risk-free rate until mine expiry. In calculating present value, these funds are discounted back at the higher risky rate. The Hoskold formula therefore tends to under-value the mine. Secondly, even if sinking funds were set up to cover the value of the deposit upon mine expiry, they would be insufficient to cover the higher cost of finding and exploiting increasingly expensive, remote, and harder-to-find economic orebodies. Finally, the invested mine capital, upon which the risky rate of return is earned, is not reduced by the amount of the sinking fund in the Hoskold approach.

Recognizing the latter problem, Morkill devised a formula[5,8] whereby the invested capital was reduced by the amount of the sinking fund:

$$V_p = \frac{E(\ (1 + f)^n - 1)}{(1 + r)^n r}$$

The terms are as defined above. However, the sinking fund concept remained. Both the Hoskold and Morkill formulas are difficult to apply in the case of a varying earnings rate.

The method favoured by the non-extractive industries and the financial community, and now finding general acceptance in mining, is the straight discount method whereby net cash flows are discounted to present values using one discount rate. The value of the mine thus calculated is termed the "net present value" (NPV). The generalized formula is:

$$NPV = \sum_{t=o}^{n} \frac{A_t}{(1 + r)^t}$$

where NPV = net present value; r = cost of capital for the firm; n = life of project; A_t = net cash inflow or outflow in period t. As Colby and Brooks[79] point out, this approach treats the mineral deposit as a depreciable asset which is gradually "worn out" through depletion. The appropriate discount rate to use is the firm's "cost of capital", the cost to the firm of acquiring the required investment funds. This cost can be determined outside the model.

The discounted cash flow rate of return (DCFROR) is another common valuation measure using the straight discounting approach. It is the rate of return earned on invested (or total) capital, and is defined as that discount rate which equates the discounted cash outflows and cash inflows (ie. that discount rate which produces a NPV of zero):

$$\text{ie.} \quad 0 = \sum_{t=o}^{n} \frac{A_t}{(1 + R)^t}$$

where R = DCFROR. This rate of return calculation can be performed on a total invested capital basis, or on an equity capital basis. Both are useful.

The DCFROR measure has several drawbacks. Firstly, the above equation will not always yield a unique ROR. This only happens when project cash inflows are followed by periods of major cash outflows, and therefore is not a common problem in mining project evaluation. A more serious problem lies in the fact that the DCFROR method assumes that funds released from the project can be reinvested at a rate equivalent to that earned by the project (ie. the DCFROR rate). In mining, where project investment alternatives are limited, this is a very poor assumption. The NPV measure, on the other hand, assumes reinvestment at the firm's cost of capital. This difference in reinvestment rates becomes critical when comparing projects of different sizes which are mutually exclusive due to budget constraints. DCFROR gives a measure of return per dollar invested, but does not consider the total amount of the investment. NPV yields a comparative total measure of each project's net return, but does not measure return per dollar invested. Both measures should therefore be calculated, and must be used intelligently according to the situation.

Another useful measure is the payback period. This is defined as the length of time a project takes to generate sufficient cash inflows to repay total initial capital expenditures. Although the measure is sometimes derived in terms of constant dollar inflows and outflows, a more useful measure is obtained by using discounted cash inflows and outflows. An example application of the payback period measure is presented in a paper by Drechsler and Schwab[87] (1975) which derives a model for regret due to investment delays under capital constraints using NPV and payback period measures.

The above measures (NPV, DCFROR, and discounted payback period) are all based on cash flow data, and therefore require no special data manipulation within the model.

3.2 Simulation Theory and Main Approaches

A simulation model is a representation of a real system in sufficient detail and accuracy to permit the observation of the behaviour of the system under various postulated conditions. Such a model thus permits the testing of the system effects under these conditions without disturbing the actual system. Where the model to be constructed is complex and will be used in several testing applications, as is the case for MINSIM, it is convenient to computerize the model.

One can define two types of simulation models: deterministic models and probabilistic models. A deterministic model is one which uses single discrete values of input parameters to generate one specific value for each output parameter. For example, in the case of a financial mine model, values for parameters such as metal price, operating and capital costs, production rate, and mine life would be input as discrete values, and the model would yield one specific value for each output parameter (eg. DCFROR).

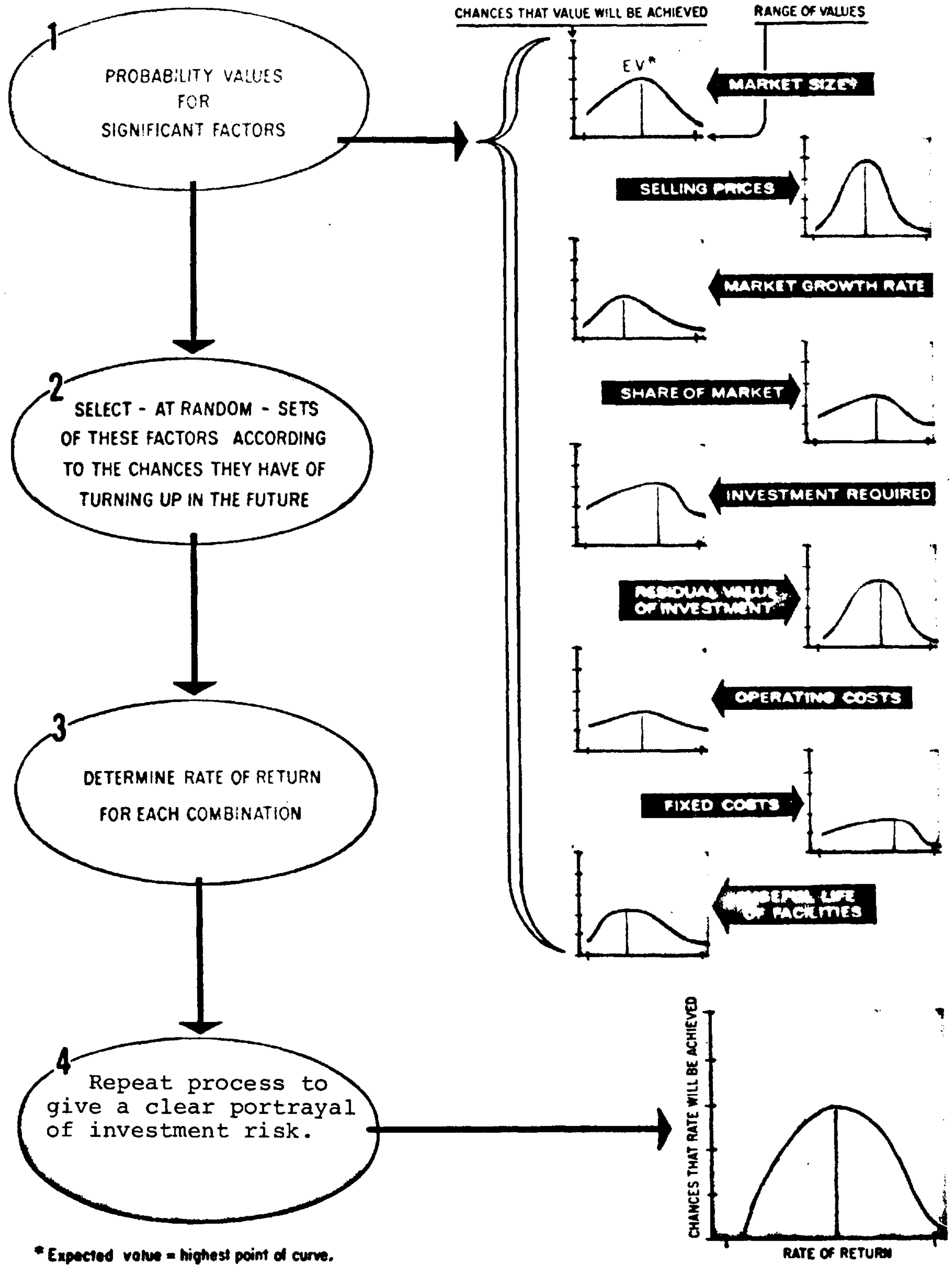
Probabilistic models, on the other hand, recognize the fact that future conditions (eg. costs, metal prices) cannot be determined with certainty. Using this approach, input variables can be assigned probability distributions on the basis of their estimated likelihood of occurrence. Values for the input variables are then chosen randomly according to their distributions using a technique known as the Monte Carlo method. The model uses these values to calculate its results. Several runs of the model using these randomly-chosen input values are made to derive a probabilistic picture of the outputs and results, thus yielding a measure of project risk. The process is shown diagramatically in Figure 1. Figure 2 illustrates the type of results that may be obtained from such a model.

The probabilistic approach uses more information than the deterministic approach, since both the range and likelihood of occurrence of the input variables are considered as opposed to a single "best" estimate. One can argue that this approach would involve a large amount of guesswork in the case of variables about which little information is available. However, it is even more important to recognize variability and uncertainty in the case of these variables. Also, due to the nature of some input variable distributions, the probabilistic approach can yield entirely different results than the deterministic model. This is because the "most likely" value as used in the latter type of model will not necessarily correspond to the mean of the variable's distribution used in the probabilistic approach. Most probabilistic models can be used as deterministic models by assigning constant values to the input variables. The increased accuracy and greater information content of the probabilistic approach must be evaluated in light of its greater cost and the availability and cost of good probabilistic input data.

Another useful approach in simulation is "sensitivity analysis", whereby the value of an input variable is varied (usually by some percentage) while other input variables are held constant. The effect of this change on model output is a measure of the sensitivity of the model system to changes in the tested variable. The relative importance of the various input variables can thus be gauged. One can

FIGURE I

A Graphic Summary of the Risk Analysis Procedure



Source: Hertz, D.B., "Risk Analysis in Capital Investment", Harvard Business Review, Vol. 42, No. 1, Jan.-Feb. 1964, pages 95-106.

FIGURE 2

The DCFROI Probability Distribution of Simulation Results

Probability of Achieving at Least The Value Shown	DCFROI Value
1.000	22.740
0.967	23.780
0.967	24.820
0.933	25.860
0.900	26.900
0.867	27.940
0.867	28.980
0.767	30.021
0.700	31.061
0.667	32.101
0.667	33.141
0.600	34.181
0.433	35.221
0.433	36.261
0.200	37.301
0.167	38.341
0.167	39.381
0.167	40.421
0.167	41.461
0.067	42.501
0.067	43.541
0.000	44.581
0.000	45.621

Source: Kim, Y.C., and Wm. C. Dixon, Mine Operations and Financial Analysis Models for Surface Mining, University of Arizona, proprietary report to Kemmerer Coal Co., December 1977.

also identify the key variables in the model system, and thereby focus attention in the areas of data gathering and further model development.

An application of sensitivity analysis is "comparative statics" wherein a system, in this case a mine, is simulated under two different sets of conditions (i.e. input parameters), and the results compared. Since the comparison is between the system under set of conditions A vs. set of conditions B, and ignores the path by which the system shifts between these states, the comparison is called "static".

Sensitivity analysis can be used in either the deterministic or probabilistic approach.

3.3 Detailed Model Analyses

The four mine models on which detailed studies were conducted are summarized and described below.

3.3.1 Kemmerer Coal Models

These models were constructed as a private-perspective valuation tool for Kemmerer Coal Co. of Frontier, Wyoming, and are applicable to open-pit coal mines, especially those utilizing truck haulage.

The modelling project consisted of four phases:

- I Coal Reserve Inventory Model
- II Mine Design and Sequencing Model
- III Mine Operations and Analysis Model
- IV Financial Analysis Model

Work for Phases I and II was awarded to MINTEC, Inc. of Tucson, Arizona, whereas Phases III and IV were done by the Department of Mining and Geological Engineering of the University of Arizona. Only the latter two phases were available, and are reviewed below.

Modelling for Phases III and IV was broken down as follows:

Phase III: 1) Haul Cycle Computation Program (DCYCLE)

2) GASP IV Open Pit Simulation Program (PITSIM)

Phase IV: 3) Financial Reports and Analysis Program (KCRISK)

4) Financial Risk Analysis Program (KCRISK)

These programs are structured sequentially such that output from one may be used as input for the next. Each program can also be used independently utilizing user-supplied data.

a) DYCYCLE

DCYCLE uses equipment manufacturer's data and road data (such as grade, surface, length, etc.) to derive travel time estimates for trucks over the entire life of a mine in one job submission. Accuracy is verified by reference to time-series studies, but the program is able to simulate situations for which no data exist. Thus, travel times can be derived for any pit configuration developed in Phase II. Switch-backs, interim stop points, and speed limits can be handled. Any equipment for which performance data is available can be modelled. Multiple runs may be used to perform stochastic simulation, treating load weights and dumping times as random variables.

b) PITSIM

PITSIM uses a simulation language, GASP IV, to determine optimum equipment mixes to meet a desired production level. The program is a discrete-time*, event-oriented model which uses travel time outputs from DCYCLE (or user-supplied data) to generate deterministic or stochastic simulations of truck-shovel operations. The model can thus test various machinery types and numbers of units, and various system designs (eg. with vs. without truck dispatcher, passing vs. no passing, etc.) to arrive at an optimal system specification. Operational details (eg. breakdowns) are easily modelled.

The model produces daily and total production data, by system machine and destination of material, as well as machinery statistics (availability, downtime, wait-time) to which costs can be applied in later stages. Detail of the program exceeds (by the authors' admissions) user patience, and data accuracy and availability.

c) REPORT

The ostensible purpose of this program is "to generate engineering cost estimates as well as financial analysis results in a <u>user specified report format</u>". Its advantages are ease of report generation, and flexibility in level of sophistication. The language used is FORTRAN. The program uses equipment types, numbers, and operating hours as determined by PITSIM, and assigns hourly operating and ownership costs to determine total mining costs. A sample of REPORT output is shown in Figure 3. The examples presented by Kim suggest that this program is merely a cost reporting system.

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*as opposed to continuous-time simulation. The latter advances the "simulation clock" on constant time increments, regardless of what events take place in the system. Discrete-time simulation only advances the clock when events occur, and thus can result in greater accuracy and/or less cost.

FIGURE 3

Sample Coal Equipment Cost Summary
(based on 10 shifts/wk.)

	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4
LOADERS: Michigan 475B				
Owner. Cost/Hr.	37.67	37.67	37.67	37.67
Oper. Cost/Hr.	54.02	54.02	54.02	54.02
Total Cost/Hr.	91.69	91.69	91.69	91.69
Number Loaders	1.00	1.00	1.00	1.00
Total Loader Cost/Hr.	91.69	91.69	91.69	91.69
TRUCKS: IH-350 PAYHAULER				
Owner. Cost/Hr.	26.41	26.41	26.41	26.41
Oper. Cost/Hr.	28.20	28.20	28.20	28.20
Total Cost/Hr.	54.61	54.61	54.61	54.61
Number Trucks	4.00	4.00	4.00	4.00
Total Truck Cost/Hr.	218.44	218.44	218.44	218.44
DRILLS: GD RDC-16B				
Owner. Cost/Hr.	9.40	9.40	9.40	9.40
Oper. Cost/Hr.	15.00	15.00	15.00	15.00
Total Cost/Hr.	24.40	24.40	24.40	24.40
Number Drills	1.00	1.00	1.00	1.00
Total Drill Cost/Hr.	24.40	24.40	24.40	24.40
DOZERS: Cat 824 RBR Tire				
Owner. Cost/Hr.	13.00	13.00	13.00	13.00
Oper. Cost/Hr.	23.24	23.24	23.24	23.24
Total Cost/Hr.	36.24	36.24	36.24	36.24
Number Dozers	1.00	1.00	1.00	1.00
Total Dozer Cost/Hr.	36.24	36.24	36.24	36.24
Total Equipment Cost/Hr.	425.86	425.86	425.86	425.86
Operating Hrs/Period	6500.00	6500.00	6500.00	6500.00
Total Cost/Period	2768090.03	2768090.03	2768090.03	2768090.03
Coal Production/Period	3000000.00	3000000.00	3000000.00	3000000.00
Mining Cost. $/Ton	0.92	0.92	0.92	0.92

Source: Kim and Dixon (1977), op. cit.

Most of the effort required in this program is in compiling ownership and operating costs for the machinery used. It should be noted that ownership costs are based on the actual machine operating life (vs. allowable depreciation pattern), and further that hourly costs represent total costs pro-rated over machine life, thus treating all equipment costs as variable with machine life. Industry practise and the nature of mining machinery suggest this is not a bad approximation. The program allows cost compilations on the user's desired level of equipment detail. However, caution must be exercised to ensure that machinery groupings are made such that machinery operating hours per day for all equipment in a group are the same. Costs are converted to a per ton basis.

The model itself is straight forward. Beyond cost compilations, there is no financial analysis in the program.

d) KCRISK

KCRISK represents the financial analysis segment of the model. Although the program is designed to perform a full scale, probabilistic risk analysis, the user can also perform conventional deterministic economic analysis by making all input variables constant. Output from a conventional analysis would simply be one NPV and/or DCFROI value whereas output from a probabilistic analysis would indicate the probability of achieving at least a given NPV and/or DCFROI for a wide range of NPV's and/or DCFROI's (see Figure 2).

A division of "state" vs. "decision" variables is shown in Figure 4. The former are non-controllable variables, while the latter

FIGURE 4

Key Variables Affecting Mining Venture Decisions

State Variables	Decision Variables
1. Grade of the Ore (Geology)	1. Tonnages
2. Price of the Commodity	2. Stripping Ratio
3. Recovery (Metallurgy)	3. Milling Capacity
4. Operating Costs	4. Discount Rate
5. Tax Rates	5. Capital Expenditure Schedule
6. Royalty	6. Initial Development
7. Depreciation & Depletion	7. Mining Sequence
8. Political	

Source: Kim and Dixon (1977), op. cit.

may be controlled to some extent. The authors suggest a more useful approach for probabilistic modelling purposes is to class variables as constant, year-to-year deterministic, or stochastic. This classification is, in many cases, somewhat arbitrary, and dependent upon model objectives and situation. The classification system must be reflected in the input data.

Physical geologic data (coal reserves, grade) and coal recovery per cent are user-supplied as stochastic variables, while technical-operations data (daily production, operating days/year, starting date) are input as constants. Note that these data fully define the mining rate and mine life. Since coal reserves are treated stochastically in this model, applying a fixed mining rate to each random coal reserve estimate chosen via the Monte Carlo method yields a different mine life.

Initial development capital, working capital, salvage values, coal price, and per ton costs (either derived from REPORT or manually input) are stochastic variables. Both depreciable and nondepreciable investment schedules for the pre-production and production periods are set out on a year-by-year deterministic basis.

The stripping ratio is input on a year-by-year deterministic basis. Although the coal reserve is a stochastic variable, it would seem that it's value does not have any effect on the stripping ratio employed.

By specifying the desired debt/equity ratio, KCRISK can be made sensitive to the firm's cost of capital. This is a useful feature, insofar as the mine financing costs to one firm may be different than to another, thus affecting the NPV of the mine. The program is designed to accommodate a wide range of tax structures, and can handle all common forms of depreciation.

3.3.2 Helliwell-Bradley Model

This model was originally set up in November 1975 to assist a committee established by the B.C. Minister of Mines in evaluating the effects of taxes and royalties on the choice of mine life, mine size, reserve volumes and ore grades for B.C. copper deposits. Much of the modelling was done by Paul Bradley, with analysis of model results performed by John F. Helliwell, Chairman of the above committee, of the U.B.C. Department of Economics. An updated version of the model[17] (January, 1977) is the one discussed here.

The model is a deterministic FORTRAN model which operates on a user-specified mine life, developing average and cutoff grades, ore reserves, and mining/milling rates from simple grade-tonnage information on the orebody and a fixed assumed strip ratio. From this, operating costs and capital costs, copper prices, and certain other financial parameters are used in deriving mine incomes. Only one orebody can be handled.

The model provides for analysis of two B.C. tax systems -- the 1975 system (with mining tax and royalties) and the 1976 system(under the Mineral Resources Tax Act). Mines with and without other income can both be handled. Rents to both Provincial and Federal Governments, and to mine developers are calculated on a net present value (NPV) basis. As well, the social NPV of the mine is derived.

The model may be run under two different optimizing decision rules: maximization of private value, or maximization of social value. This permits approximations of private as well as true economic costs of various tax systems, cost changes, copper price variations, etc.

The model may be divided into two components, an operating-production sector, and a financial analysis sector. This distinction is not made in the actual organization of the program, but is useful for clarity and for purposes of this discussion.

1. Operating-Production Sector

Briefly, this section takes the physical characteristics of the orebody (stripping ratio, and lognormal grade-tonnage relationship) as supplied by the user, develops per ton operating costs, and uses this information to establish ore reserves, cutoff grade, mill rate, and the sequence of mining of the orebody. The procedure is outlined below.

First, unit operating cost of mining and milling per ton of total material is derived from user-supplied mining and milling costs per ton of ore, multiplied by the stripping ratio. The stripping ratio defined as tons of overburden plus ore mined per ton of ore milled, and is input by the user as a constant for the entire orebody over its operating life. This simplification is not generally a good approximation of real operations, and may significantly affect valuation measures.

Cutoff grade is then determined as the grade at which revenue per ton of ore milled equals the cost of mining and milling that ton of ore, as calculated above. Where a production-based royalty is in effect, royalty charges are included in per ton costs. Ore tonnage (i.e. mineable reserves) is then calculated by reference to a lognormal grade-tonnage relationship which specifies the tonnage of ore mineable at and above a given cutoff grade. This relationship is defined by user inputs for the mean and standard deviation of the deposit's grade.

Since the mine life is user-specified, the ore mining and milling rates are simply the reserves divided by the mine life.

To calculate the annual average grades of ore mined, the following procedure is used. The orebody is assumed to be mined in a number of steps, with the richest portions of the orebody mined in earlier steps. This corresponds to financial theory which suggests that present values are increased when cash inflows occur in earlier periods. Mining companies do tend to operate in this way (to the extent possible) for the above reason, and also to take advantage of early-year tax deductions, as well as to benefit from greater early-year cash availability for initial break-in and operating expenses. The mine life is divided into periods according to the number of steps mining is to be performed in. For each month, the grade of ore mined is calculated by referring to the lognormal grade-tonnage relationship and the percent of the ore reserves mined. The quantity of copper mined each month is calculated from the month's grade and the (constant) mill rate. This is aggregated over all months, then over all years comprising the "step". An average grade for that step is found by dividing the total copper mined by the total ore mined. This is done for each mining step.

Although one can imagine a situation wherein the miner is able to mine the richest kernel of the orebody on the first day, and mine at the cutoff grade on the closing day, this seldom conforms to reality. The above procedure recognizes some choice in which portions of the orebody are mined first, while not taking this idea to extremes.

Provision for mine management reaction to mine operating and financial performance is limited to a function which shuts down the mine temporarily in the event that revenues cease to cover variable costs (including equipment replacement). No adjustment of ore grade cutoffs to changing economic factors is allowed.

2. Financial Analysis Sector

This section of the model develops all the necessary stock and current accounts, and performs financial and efficiency analyses from both private and social viewpoints.

Development of the accounts is fairly straightforward. Operating costs are input on a unit basis. Initial capital expenditure is calculated from a cost per ton of material mined plus a cost per ton of ore milled, with provision for economies of scale in the latter through an exponent. Alternative capital costs can be modelled through use of an adjustment factor. The initial capital costs are spread evenly over a three year pre-production period. All costs are user-specified, and are inflated over time within the model, using a user-input inflation index.

Development expenditures are taken as a user-specified fraction of initial capital cost, as are ongoing (replacement) expenditures. The stock of unpaid debt is a running total of expenditures funded from debt, as determined by a user-specified debt/total capital ratio, less the principal paid back each year. It is assumed that all debt is retired at mine expiry.

This section of the model also develops a discount rate for present value calculations. It has two user-specified components -- the real rate of social time preference, and the expected rate of inflation. The social time preference discount rate "reflects society's evaluation of the relative desirability of consumption at different points in time"*. The expected rate of inflation expresses future dollar values in terms of constant or "real" dollars. The <u>product</u> of these two rates is a "real" dollar measure of the compensation demanded by society for foregoing consumtion in one time period in favour of consumption in a later period.

Several financial analyses are carried out by the model. These are reviewed below.

a) Cost of Copper Extraction:

This is measured from a private and social viewpoint. The private cost is merely the discounted operating costs incurred in extracting the metal, divided by the discounted volume of the metal. The private cost will

*M.S. Feldstein, "The social time preference discount rate in cost-benefit analysis", <u>Economic Journal</u>, vol. 74, 1974, pp. 360-379.

increase with decreasing ore grades mined. The social cost of extracting a pound of copper, however, includes 1) the private after tax cost of funds employed, plus 2) the opportunity cost of funds employed as measured by the corporate tax generated by the capital if it had been employed in another industry, plus 3) economic depreciation, plus 4) operating costs.

Note that, for both the above measures, costs of extraction are discounted at the full rate (social time preference X inflation) while copper volume is discounted at the social time preference rate only. The discounting of copper volume takes recognition of the fact that different extraction patterns will result in different consumption patterns over time. In order to compare different extraction patterns, the "cost" of foregone consumption must be measured. This is done by discounting, using copper volume as a proxy for copper value. Since the"real" (constant dollar) value of a commodity is unaffected by inflation, the social time preference rate is the applicable discount factor to use.

b) Rents:

Economic rents are those returns in excess of the returns available in the best alternative. This model calculates three rents:

i) Rents to the mine developer

This is calculated as the present value of mine income less operating costs, economic depreciation, after tax cost of capital, and royalties and taxes.

ii) Rents to the Federal Government

This measure is the discounted value of corporate taxes paid to the Federal Government by the mine less the federal share of corporate taxes which would have been paid if the capital had been invested in another industry.

iii) Rents to the B.C. Government

This is the discounted value of the B.C. share of corporate taxes plus B.C. mining taxes plus all royalties less the B.C. share of corporate taxes which would have been paid if the capital had been invested in another industry.

The above rents thus illustrate the returns to the three parties involved which are in excess of the returns which would have been obtainable in another industry. It should be noted here that, in actual practice, mining investment capital may be more mobile between regions <u>within</u> the mining industry than between industries within B.C.

c) Private and Social Net Present Values (SNPV) of the Mine: The private net present value is merely the discounted net cash flows accruing from the mining operation. The value of the mine to society, however, is the discounted value of gross mine income less operating costs, economic depreciation, the cost of funding (comprised of the after-tax cost of funds to the firm plus the buying power of the funds lost due to inflation), and any undepreciated residual value of capital plant or equipment which is not saleable or otherwise useable at the expiry of the mine. Taxes and royalties are ignored as they represent transfer payments between parties within the social system. Although the social NPV as treated in this model accounts for the opportunity cost of capital, one may have objections about its lack of treatment of the opportunity cost of labour. According to conventional theory in social benefit-cost (SBC) analysis (and this is essentially what the SNPV measure is), the opportunity cost of labour is its wage at the next best alternative. This model values labour opportunity cost at its full wage in the mine as the labour component of operating costs. It may be that, in fact, may of those employed at the mine would be unemployed, or employed at a lesser wage, in the mine's absence. Thus, to value the cost of labour at its full wage rate may tend to undervalue the social NPV of the mine in some circumstances. On the other hand, one could argue that capital invested in mining generates less employment per dollar than capital employed elsewhere, yet no recognition of this fact is made.

By using two optimization criteria, namely private NPV and social NPV, the Helliwell-Bradley model sought to measure:

i) the cost to society of having a private company operate the mine (as measured by the difference between the social NPV under private NPV maximization and the social NPV under social NPV maximization);

ii) the savings accruing to a private company from being able to maximize private NPV rather than being subject to social NPV maximizing rules, as indicated by the private NPV values under each of the decision criteria.

3. General Comments

By varying the user-specified mine life, one can determine, for a given orebody, the optimal rate of extraction and cutoff grade for either the mining company or society.

The outputs of the model include the aforementioned financial measurements as well as cutoff grade, mill rate, total initial capital cost, and ore reserves. Output in the form of cash flows, pro forma statements, and year-by-year operating costs and figures which may be useful in analysing a specific mining venture are not developed.

The operating-production sector of the model is inadequate for MINSIM purposes. The assumption of constant strip ratios and a simplified approach to sequence of mining of the orebody are too general and unrealistic to permit their application to actual operating mines. Bradley has had abundant feedback from industry and mining engineers on this point, and is in the process of developing a system-optimizing model for mine design and production scheduling for a hypothetical orebody. Although not applicable to modelling a specific mine, the model information, which will be available later this year, may suggest improved ways to derive tonnage and cutoff grades <u>over time</u>, and may also provide better interactive operation features (eg. changing cutoff grade instead of initiating temporary mine closure).

3.3.3 ERDA's Coal Mine Cash Flow Analysis Model

The "Cash Flow Analysis" (CFA) Model[22] was developed, under contract for the Energy Research and Development Agency, by Fluor Utah, Inc. (contractor), and Bonner and Moore Associates, Inc. (major sub-contractor), as an integral part of ERDA's investigation into "Economics of Large-Scale Surface Coal Mining Using Simulation Models".

The purpose of the overall study is to:

1. estimate expected coal mining and processing costs (especially for use in coal energy conversion technology analysis), and investigate their sensitivity to changes in mining and financial parameters; and,

2. provide industry with planning and analysis models for design and equipment selection.

The study was conducted over 42 months at a cost of $2.5 million.

The following major coal mining methods are investigated:

1. area stripping with draglines
2. contour stripping with draglines
3. area stripping with trucks and shovels
4. mountain top removal
5. multiple dipping seam mining

These methods are modelled and applied to several potential coal producing regions of the United States.

The models are of two types. Micromodels were constructed for detailed simulation of individual mining operations (eg. overburden removal, coal loading and haulage, etc.) using specified equipment. The user is required to make equipment selections and design decisions. These models can be used for detailed analysis of a mining operation at the engineering stage of project development.

The macromodels simulate an entire mining complex using a specified mining method. They provide an order-of-magnitude estimate of mining cost, and require only 7 mining and 9 financial parameter inputs. The remaining variables assume default values which can be replaced by the user. Macromodels were only constructed for mining methods 1, 2, and 3 above.

Both types of models utilize the CFA model to derive financial mine evaluations. Output from the macromodels may be used directly as input to the CFA model. Micromodel outputs require analysis and data preparation for use in the CFA model. The CFA model can also be used independently by using manually-prepared input data.

The study was accomplished in two phases. Phase I consists of a review of coal resources, mining and processing systems and costs, factors which affect coal mining, and the computer systems status at the end of Phase I (see Appendix C: Phase I Report List). The second phase consists of two parts: a presentation of test case results using the various models developed, and user manuals describing the functions and access to the models. Phase II reports are as listed in Appendix D.

The Cash Flow Analysis Model utilizes data input at the user's level of detail to derive a comprehensive set of financial statements and valuation measures. Since the model was constructed for the purpose of <u>costing</u> a coal supply for use in energy conversion technologies, the approach taken is to set the DCF rate of return to some desired level, and then find the coal price which yields this return. However, the model can also be used to derive a DCFROR given a certain coal price. The model mechanics of this operation are actually simpler than for the derived coal price approach, and more applicable to the British Columbia metal mine situations. The model is deterministic and employs a private valuation perspective.

The CFA model is more sophisticated and comprehensive in its financial and cash flow calculations than other models studied. The following is a condensed step-by-step description of the model operation logic:

1. Input data is read in from three files. They are:

   a) Personnel File - contain union grade classifications, wages, etc.;

   b) Equipment File - contains equipment types, costs, maintenance and operating labour requirements, operating characteristics and capacities, numbers, etc.;

   c) Control File - specifies outputs desired, some financial parameters definitions, and model operating controls (e.g. number of cases run).

2. Using the above input information, the production, investment, depreciation, and operating cost schedules for each year are calculated for each mining function. The mine project definition may include any combination of the following mining functions (operations):

   Overburden Drilling and Blasting
   Overburden Removal
   Coal Drilling and Blasting
   Coal Loading and Hauling
   Land Reclamation
   Coal Handling and Preparation
   General and Administration

3. Insurance and property taxes are calculated as a user-specified fraction of total undepreciated investment. Home office costs are calculated as a user-specified fraction of total operating costs.

4. Where the user wishes to determine the selling price necessary to yield a given rate of return, all investments are assumed to be financed from paid-in capital (i.e. 100% equity). Income statements are then developed at an initial assumed selling price, and resultant cash flows are discounted to derive net present value. The selling price is adjusted and the procedure repeated until the NPV is zero at the given required rate of return.

5. Sources and uses of funds accounts are developed, using short term debt as the plug (balancing) account.

6. Short term debt requirements and interest charges are then determined. Since the latter will change the income, steps 4, 5, and 6 are repeated until short term interest charges in subsequent interations are within 5% of each other. Steps 4, 5, and 6 are ignored in the case of a known or user-specified selling price.

7. Investment expenditures are allocated to long term debt and paid in capital according to a user specified ratio. Long term debt repayment and interest charges are calculated.

8. Income statements and sources and uses of funds statements are developed, using short term borrowing as a balancing or "plug" figure, and using the user-specified selling price, or, in the case of an unknown initial price, that price determined in steps 4, 5, and 6. Again, this process is repeated until short term interest charges stabilize for subsequent interations.

9. The balance sheet accounts are completed and the debt/equity ratio is checked. The model provides the user with the option of ensuring that the debt/equity ratio will not exceed a maximum value in any year.

   When this option is "on", the model calculates the debt/equity ratio for each year. If the calculated ratio exceeds the desired ratio, the model takes one or more of the following actions to reduce the ratio:

   a) reduce the dividends,

   b) use surplus cash to increase debt repayment, and/or,

   c) increase paid-in capital.

   These steps are taken to the extent possible in the order listed. The model then redevelops the pro-forma schedules; however, the sales price is fixed at the previously determined value.

10. Return on investment (ROI) and return on paid-in capital (ROPIC) are oalculated.

The above description highlights three financial features of the model: 1) its ability to calculate a required selling price given a target rate of return or the rate of return at a given selling price; 2) its ability to balance cash flows internally by use of short term debt as a plug account; and, 3) internal capability for maintainence of a desired debt/equity ratio.

The outline makes no reference to coal reserve tonnage and mine life. These factors are determined by the appropriate micro-or macro-models.

The model has the following additional features and options applicable to the user's desired level of equipment breakdown detail:

1. All equipment operating and investment unit costs, an labour rates, by union grade, are supplied in January, 1975 dollars using Southeastern U.S. baseline figures. These base figures can be adjusted by regional adjustment factors. Escalation factors define cost behaviour over time and can be scheduled to start in any year of the operation. Usage factors can be applied to account for severe operating conditions.

2. Production build-up and shut-down patterns in each operation can be accounted for, including build-up equipment purchase patterns. Deferred purchases can be made. Operational inefficiencies at start-up can be modelled. The life of a specific operation must be specified, but different operations may have different lives.

3. Replacement investments are calculated and provided for internally through use of equipment depreciation life (in hours). Equipment investment costs do not include tire costs, as these are considered an operating expense. Non-depreciable assets are provided for.

4. Actual equipment capital expenditures are modelled according to the purchasing method (e.g. "with order", "with delivery" or in "equal payments" over the purchase lead time, which is user-specified).

5. Construction loans and loan interest can be determined (most applicable to buildings).

6. The depreciation method desired (straight-line, declining balance, or double declining balance) is user-specified.

7. Salvage values may be user-specified as a percentage of purchase price.

8. The quantity of equipment and number of fleet spares must be supplied by the user (or through the macro or micro models).

9. Operating labour costs and requirements are determined from machine operating hours, labour requirements, and wage schedules. Various shifts and work-weeks can be specified.

10. Other operating costs can be input and adjusted on an equipment-specific basis, and may be broken down as follows:

    Maintenance material costs
    Fuel costs
    Tire costs
    Electrical power costs
    Water costs
    Other costs

11. Maintenance labour costs and requirements, and other maintenance costs are derived and broken down similarly to operating costs.

12. Discount rates, dividend payout, interest rates, and tax rates are all user-specified.

In addition, the model permits analysis of the following government policy variables:

- various depreciation methods
- land reclamation costs
- safety regulation costs
- leasing of federal lands
- state severence taxes
- royalties
- federal tax changes
- price subsidies
- construction grants and subsidies

Input requirements for the model can be substantial where detailed breakdown is desired. A wide variety of output is available, including a complete set of year-by-year financial statements, personnel lists, investment lists, and production reports. Return on investment includes long term interest charges, whereas ROPIC does not. Net present value is not explicitly calculated.

The model is non-optimizing, but merely reflects the user's equipment choices and assumptions.

3.3.4 J.K. Wright's Computer Valuation Model

This FORTRAN model[24] was written as an M. Sc. thesis at U.B.C. It is basically a reporting model with limited internal capabilities. Nonetheless, it does contain some interesting and possibly useful sections. The model is deterministic and uses a private financial analysis framework. The model is not used by, or associated with, Wright Engineers Ltd. in present or modified form in any of their mine models.

Mines consisting of up to ten orebodies can be handled over a mine life of up to 20 years. The model considers eight "paying" metals* conprising copper, lead, molybdenum, or zinc concentrates, with the ability to calculate a wide range of penalties and bonuses for other materials within various smelter contract structures.

The model consists of a main program comprised of 13 subroutines corresponding roughly to income statement items. The subroutines are:

METPRI - reads and writes all metal prices
MINCOS - calculates annual mining costs
GRADES - calculates mill feed grades
MILCOS - calculates annual milling costs
OTHCOS - calculates other direct operating costs
REVCOP - calculates revenue from sale of copper concentrates
REVLED - calculates revenue from sale of lead concentrates
REVZNC - calculates revenue from sale of zinc concentrates
REVMOL - calculates revenue from sale of molybdenum concentrates
SHIPCO - calculates annual shipping costs
DEPN10 - calculates annual class 10 asset depreciation
DEPNIL - calculates annual class 10 mill asset depreciation
DEPN20 - calculates annual class 20 asset depreciation

The main program uses the above information to calculate provincial

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*the "paying" metals are copper, gold, silver, lead, zinc, molybdenum, cadmium, and bismuth.

and federal taxes (as of 1973, and incorporating contemplated changes at that time), and calculates annual cash flows.

Prices for the eight paying metals are user-specified throughout the mine's life.

Geologic reserves are specified for each orebody. Mineable ore is calculated by use of a percentage extraction factor for each orebody. Dilution of the ore in each orebody by waste rock is expressed as a percentage of the ore. All the above are input as constants by the user.

The mining rate for each orebody for both waste and ore is user-specified on a year-by-year basis. Annual mining costs are calculated by applying exogenously-determined per ton mining costs for waste and ore for each orebody to the daily mining rates, and multiplying by the working days per year. Each orebody is mined to exhaustion in the order specified by the user. Although the mining rate and mineable ore tonnage should effectively determine the mine's operating life, this too is user-supplied. There is no internal financial criterion employed to define the limits of economically mineable ore. All materials defined by the user as extractable ore are mined. Milling costs are calculated by applying a per ton cost to the annual mill feed tonnage (defined as the sum of the ore plus diluting material mined). Waste and ore mining costs, and milling costs can be escalated by their respective constant incremental or compound factors. The treatment of"other costs" is the same as for the above costs. Shipping costs are specified on a per wet ton basis for each type of concentrate, and can be escalated as above.

Ore grades are supplied by the user for each of the eight metals by orebody and by year for both ore and diluting material. Revenues are therefore calculated from metal prices, grades, ore and diluting material tonnages produced, and user specified mill recoveries for each metal according to the type of concentrate produced. As mentioned earlier, revenue calculations are based on actual smelter contract details. Figure 5 outlines the provisions in the model for paying metals, bonus metals and materials, and penalty metals and materials for each type of concentrate. There is considerable flexibility possible in the method of penalty calculations. In addition, allowances are made for treatment charges, selling commissions, and dusting losses, and for any penalties, bonuses or charges not otherwise covered.

Depreciation charges for tax purposes are calculated based on user-supplied initial capital costs and ongoing expenditures by asset class. Capital cost allowance rates are fixed internally in the model.

The main program aggregates and massages the above revenue, cost, interest, and depreciation data, together with federal and provincial tax parameters (supplied by the user) to derive provincial and federal taxes. Although one may change the various tax rates used in the model via input parameters, the structure of the program permits no flexibility with respect to structural tax changes. It thus adheres to the structure in force in 1973 and reflects some changes contemplated at that time. Although calculations are basically correct, they are applicable only to the case of a mine operator with no other taxable income - not a common case in B.C. Net profit after taxes is calculated by year.

FIGURE 5

Smelter Contract Metals and Materials

	Paying	Bonus	Penalty
Copper Concentrate	Copper Gold Silver		Silica deficiency Zinc Lead Nickel (and Cobalt) Arsenic Antimony Bismuth Moisture
Lead Concentrate	Lead Gold Silver Zinc Bismuth Copper	Silica Lime	Iron Arsenic Antimony Alumina Moisture
Zinc Concentrate	Zinc Lead Gold Silver Cadmium		Iron Moisture
Molybdenum Concentrate	Molybdenum		

The gross cash flow (i.e. before uses) is calculated by adding back before-tax non-cash outflows (depletion, depreciation) to net income after tax. The net cash flow is derived by subtracting all capital expenditures and loan principal payments from gross cash flow. The annual net cash flows are summed over the life of the project to derive "total net cash flows". Since this figure uses undiscounted cash flows, it is not a meaningful valuation measurement. Furthermore, there is no allowance for any recovery of asset values after expiry of the mine (which may be reasonable in many cases) or recovery of working capital on hand upon expiry (this is not reasonable). No other valuation measures (such as D.C.F. rate of return or payback period) are calculated.

There is no provision for temporary or permanent closure of the mine during its rigid-term lifetime in the event that mine revenues do not cover variable costs, or a severe cash flow problem (in the case of a single mine income operation as examined here) is encountered.

Output tables are produced on the following data. All current account schedules are produced by year. Production, milling, and reserve status schedules and grades mined are presented for each orebody. The metal price list and the net cash flow are tabulated by year.

3.4 Other Whole System Valuation Models

Several models less detailed, broad in scope, and/or well-documented than those reviewed in the previous section were studied.

Some useful features of each are summarized below.

3.4.1 PSI's "COAL" Model[38]

This computer model makes economic appraisals of coal leases from a private perspective. The program source code language is FORTRAN. Although the source code is not available, the user manual is very well documented and easy to understand, and program functions are therefore easily constructed from it if desired. An input variable taxonomy is included in the user manual.

The model is basically a reporting/analysis tool which operates deterministically on specified operating, production, and financial data. All costs, production rates, stripping ratios, financial charges, and capital expenditures are exogenous inputs to the model. It therefore has no internal mine design or production scheduling capability.

The advantages of the model are as follows:

1. ease of use and flexibility in input format;
2. modest amount of input required;
3. flexibility with respect to desired user level of detail;
4. detailed capability for breakdown of ownership, capital, operating, and income share interests. Perspective is from the viewpoint of a coal lease participant (eg. a joint venture member);
5. detail and flexibility possible in loan agreements, depreciation methods, etc.;
6. detail possible in various tax calculations and bases.

Sensitivity analysis is easy to perform and possible on a number of tax policy parameters.

7. detail available in output options, including a number of financial measures and year-by-year cash flow elements and income statements;

8. flexibility available in specifying input parameter patterns over the mine life;

9. provision for other sources of income, tax deductions, charges, etc.

Thus although the model is based on coal mining and coal mine legislation, the way in which some financial calculations are made and the flexibility offered may be of some use in MINSIM model construction.

3.4.2 Wright Engineer's Quick Capital Cost Estimate[43]

This proprietary program provides an order-of-magnitude type estimate (± 30%) capital investment costs of Canadian or foreign mines, mainly for use by the mineral exploration industry. Very general descriptions of mine location, milling process to be used, physical orebody characteristics, and production rates are input, and costs based on Canadian data and experience are applied to the input data to derive a deterministic capital cost estimate. The model is therefore static and non-optimizing. The capital cost estimate is built up from the items shown in Figure 6. The article referenced thus provides a useable cost centre breakdown, and identifies the main variables of importance.

FIGURE 6

Components in Wright's Quick Capital Cost Estimate

HYPOTHETICAL MINE CANADA		16 DEC 1976
PROJ. NO.	RUN NO.	8000 TONS PER DAY ($ MILLIONS)
MINING DEVELOPMENT		$ 13.477
CRUSHING AND SCREENING		$ 9.541
CONCENTRATING		$ 13.649
WATER SUPPLY		$ 1.802
TAILING DISPOSAL		$ 2.534
POWER SUPPLY, SUB-STATION AND DISTRIBUTION SYSTEM		$ 6.103
ACCESS ROAD, SURFACE VEHICLES AND FUEL STORAGE		$ 1.050
ANCILLARY BUILDINGS		$ 3.582
EMPLOYEE HOUSING		$ 10.006
SUB TOTAL		$ 61.715
WORKING CAPITAL AND INVENTORY		$ 6.172
ENGINEERING AND CONSTRUCTION MANAGEMENT		$ 4.690
ADMINISTRATION COSTS		$ 3.135
INTEREST CHARGES		$ 4.783
TOTAL CAPITAL COST		$ 80.495

Source: Wright Engineers Ltd., "Computerized Quick Capital Cost Estimate for International and Domestic Mining Projects", Van., B.C., January 1977.

3.4.3 Roman and Becker's Monte Carlo Simulation Model

This FORTRAN program is a straight forward probabilistic model for performing mine valuations. Virtually all important mining variables are user-input. Ore grade, and metal recovery and price may be specified for two metals. Exploration and development costs, and all operating and capital costs for mining and milling are user-specified. Tonnage and mining rate are both user-supplied, thus fixing mine life. Royalty charges are specified by the user. The tax rate is assumed to be 50%. Working capital and miscellaneous costs are estimated at 15% and 20%, respectively, of annual sales. The model accepts input data in rectangular, normal, or skewed distributions for return on investment (ROI), and cash flow statements. A sensitivity analysis option is also available, in which input values are altered by ± 10%.

Although the model does not perform detailed analysis and operates strictly on user information, the program source code is simple and clarifies the form and use of the Monte Carlo simulation technique and sensitivity analysis.

3.4.4 Azis et al : Computer Simulation Model[28]

This model employs Monte Carlo simulation, based on the Roman and Becker model, to derive probabilistic rate of return estimates for mineral deposits in the initial and very preliminary stages of evaluation. As in the Roman and Becker model, sensitivity analysis may be performed on the input variables. A taxonomy of the 38 input variables is supplied in Figure 7. No source code is included.

FIGURE 7

Variables that can be introduced into the model for the assessment of a mineral deposit

Variable	Description	Unit
1	Tonnage of deposit	(tons)
2	Grade of deposit - metal A	(%)
3	Grade of deposit - metal B	(%)
4	Grade of deposit - metal C	(%)
5	Grade of deposit - metal D (silver)	(ozs/ton)
6	Grade of deposit - metal E (gold)	(ozs/ton)
7	Mine recovery - metal A	(%)
8	Mine recovery - metal B	(%)
9	Mine recovery - metal C	(%)
10	Mine recovery - metal D (silver)	(%)
11	Mine recovery - metal E (gold)	(%)
12	Mill recovery - metal A	(%)
13	Mill recovery - metal B	(%)
14	Mill recovery - metal C	(%)
15	Mill recovery - metal D (silver)	(%)
16	Mill recovery - metal E (gold)	(%)
17	Smelter recovery - metal A	(%)
18	Smelter recovery - metal B	(%)
19	Smelter recovery - metal C	(%)
20	Smelter recovery - metal D (silver)	(%)
21	Smelter recovery - metal E (gold)	(%)
22	Price - metal A	($/lb)
23	Price - metal B	($/lb)
24	Price - metal C	($/lb)
25	Price - metal D (silver)	($/oz)
26	Price - metal E (gold)	($/oz)
27	Mining cost	($/ton)
28	Milling cost	($/ton)
29	Smelting cost	($/ton)
30	Exploration cost (on-property)	($/ton)
31	Development cost (on-property)	($/ton)
32	Administration cost	($/ton)
33	Interest charges	($/ton)
34	Exploration expenditure (pre-production)	($)
35	Development expenditure (pre-production)	($)
36	Mining rate	(tons ore/day)
37	Capital expenditure - mine	($)
38	Capital expenditure - mill	($)

Source: Azis, A., C. Janakiraman, and A.B.T. Werner, "Computer Simulation Model for the Assessment of Mineral Resources", Department of Energy, Mines and Resources, Ottawa, Canada.

3.4.5 Trafton and Sheinkin's Mine Valuation Model[42]

This article (source code not included) outlines the capabilities of an Amax computerized valuation model (1969). As is the case with the previously-discussed models in this section, this model operates on completely user-specified data. The deterministic analysis performed is fairly straight forward. The following interesting features of the model are apparent from the input data outline in Figure 8.

1. The classification scheme itself is a useful division of the types of data.

2. The "funding" inputs permit control of debt and equity sources, and calculation of financing charges and the time horizon of these charges. Various kinds and sources of debt can be considered.

3. The tax inputs, although not directly applicable to MINSIM circumstances, illustrate a modular approach to tax options that may be useful.

4. The option of employing various discount methods, costs of capital (discount rates), and bases for ROI (equity vs. total investment) permit more comprehensive financial analysis to be made.

5. The specification of ownerships in various aspects of the mining venture allows the model to evaluate the financial positions for every co-venturer. The model can handle these financial arrangements:

a) mineral products distribution
b) book earnings distribution
c) dividend distribution
d) lump sum payments
e) distribution of cash flows
f) depreciation and depletion distribution
g) capital allotments

This is a useful option were joint ventures and partnerships are to be analysed.

Outputs include discounted cash flows, pro forma income statements, return on equity and total investment, and net present value.

FIGURE 8

Input Variables for the Trafton-Sheinkin Model

TECHNICAL AND OPERATING DATA

Mine	Ore Reserves Production Rate Ore Grades
Mill	Concentrate Grades Recoveries Concentrate Ratio
Smelter	Product Grade Recoveries Losses
Refinery	Recoveries Losses

COSTS AND PRICES

Pre-production Capital Expenditure
Working Capital
Acquisition Cost
Exploration
Mine Development
Operating Cost
Overhead Cost
Royalties
Copper Price
Silver Price
Gold Price

Source: Trafton, B.O., and Moshi Sheinkin, "Computer Applications in Financial Analysis" in *A Decade of Computers in the Mineral Industry*, 1969.

Figure 8 (Cont'd)

FUNDING

Equity Financing
Debt Financing:

- Type of Debt
- Amount
- Interest Rate
- Start of Loan (year)
- Start of Payback (year)
- Length of Payback Period (years)
- Manner of Repayment (schedule)

TAX STRUCTURE

specific to locale

FINANCIAL AND ACCOUNTING FACTORS

Detail of Book Allowances
Method of Discounting
Items Included in Discounting
Type of Return on Investment (ROI)
Cost of Capital

OWNERSHIP DISTRIBUTION

Share of Equity
Share of Profits
Share of Depletion Allowance
Share of Depreciation

3.4.6 Peiker-Forsythe (AMAX) Financial Mine Model[37]

This probabilistic model employs the same approach as the Roman and Becker model in calculating rate of return probabilities from exogenously-determined cost and operating/technical inputs. The inputs used are listed below:

a) grade
b) recovery %
c) tonnage
d) operating costs
e) working capital
f) machinery and equipment cost
g) buildings cost
h) water cost
i) land cost
j) pre-production expense
k) sales price

The U.S. tax system with simplifying assumptions is used. A sensitivity analysis option is available. The program source code is proprietary. The article notes the importance of interdependence of input variables (eg. grade vs. recovery, tons vs. operating costs) when using probabilistic simulation, and suggests inputing more than one probability distribution for certain input factors. For example, the choice of a random value for recovery could depend on the random value chosen for grade in a given run:

ie.

Grade Value Chosen	Recovery Distribution to be Sampled
<0.35	distributicn A
0.35 - 0.45	distribution B
>0.45	distribution C

It is necessary to recognize these relationships either within the model, or external to the model by altering various input parameters accordingly.

3.4.7 Birtley-RTZ Coal Model[29]

The proprietary program is written in FPS (Financial Planning Simulator), a language developed by Rio Tinto North American Services Ltd. (RTZ), and serves as a tool for "ballpark estimates on the potential viability of future projects" in Western Canada. The model performs sensitivity analysis, and can be made to incorporate risk analysis through Monte Carlo simulation. It operates on exogenous cost and operating/technical data supplied on an aggregate level. Comments on the organization and classification of model inputs (shown in Figure 9) are summarized below:

1. Exploration stage investments are classed according to their tax status.

2. Development stage investments are classed according to mine, transportation, or townsite expenditures, with provision for grants and mortgage loans for the latter.

3. Working capital is built up from component items of inventory, stores, account receivable, and salvage value.

4. A debt-equity ratio can be specified, with provision for debt repayment scheduling and debt charges.

Output consists of a pro forma profit and loss statement, a detailed tax statement, a funds flow statement, and NPV and DCFROR measures.

FIGURE 9

Birtley/RTZ Coal Model Inputs

A. Pre-Production Investment

1. Exploration Stage

    a) exploration, bulk sampling, coal testing, etc. (100% tax write-off);
    b) feasibility studies, consultant fees, design, etc. (30% capital cost allowance.

2. Development Stage

    a) mine equipment, plant, shops, offices, etc.;
    b) townsite, grants, mortgage loans, etc.;
    c) railroad construction.

B. Production Costs

1. Volumes, Prices, and Yields

2. Mining Costs

    a) rock
    b) coal
    c) metallurgical coal processing
    d) oxidized coal processing
    e) reclamation

3. Overhead, Shipping, Administrative, etc.

    a) overhead and administration
    b) rail transportation
    c) terminal
    d) sampling and assay
    e) commission
    f) moisture property

C. Working Capital

1. Raw metallurgical coal inventory

2. Raw oxidized coal inventory

3. Clean metallurgical coal inventory

4. Clean oxidized coal inventory

5. Stores

6. Accounts receivable

7. Residual salvage value

D. Royalties and Taxes

- applicable to coal only

E. Other

1. Debt Financing

   a) starting year
   b) D/E ratio

2. Interest on Borrowed Capital

3. Discount Rate Used

4. Fixed Parameters (for tax rates and allowances).

3.4.8 Michelson et al Models for Taconite Iron Ore Valuation[33,34]

These models were developed for two reasons:

1. to develop a procedure for iron ore resource evaluation;
2. to demonstrate (apply) the procedure in the evaluation of Mesabi Range taconite iron deposits.

The procedure consists of three models:

1. Quality Model - evaluates a given deposit on the basis of recoverable iron content, concentrate iron content, and ore probability factor (as determined by silica content).

2. Discounted Cash Flow (DCF) Cost Evaluation Model - determines the unit cost of producing iron from a given deposit.

3. Economic Availability Evaluation - assesses the economic availability of the iron ore in terms of unit cost and resource quantity/quality.

The Quality Model is iron-specific. The Economic Availability Evaluation concerns itself with the evaluation of an entire region on the basis of preliminary resource quantity and quality data and unit cost criteria. The DCF Cost Evaluation Model is of most interest from a MINSIM viewpoint. It develops the cost of producing iron by assuming a required rate of return, and calculating the sales price (i.e. cost) required to yield this rate given exogenously-determined cost data. This method is similar to that employed (optionally) in the ERDA coal model. The model uses Monte Carlo probabilistic analysis. As shown in Figure 10, model inputs fully define operating/technical and cost parameters on an aggregate basis.

FIGURE 10

Component Cost Input to DCF Evaluation Model

Component	Units
Capital investment	Dollars
Plant capacity	Tons/year (crude)
Production costs	
Mining	Dollars/ton (crude)
Beneficiation	Dollars/ton (crude)
Supervision and management	Dollars/ton (crude)
Pelletizing	Dollars/ton (product)
Stripping	Dollars/cu yd (equivalent surface)
Transportation	Dollars/ton (product)
Franchise costs	
Average state and local taxes	Dollars/ton (product)
Royalty costs	Dollars/ton (product)
Computation factors for Federal Income Tax	Percent (taxable income)
Federal Income Tax rate	Percent (gross income for depletion)
Gross rate for depletion	Percent (net income for depletion)
Net rate for depletion	
Cash flow parameters	
Rate of return	Percent (capital investment)
Repayment period	Years
Resource variables	
Recoverable iron content	Percent (crude)
Concentrate iron content	Percent (concentrate)
Equivalent stripping ratio	Cu yd (equivalent surface)/ton (product)
Depreciation method indicator	(straight line, double declining, or sum of years digits methods, respectively)

Source: Michelson, R.W., and H.J. Polta, "A Discounted Cash Flow Model for Evaluating the Cost of Producing Iron Ore Pellets from Magnetic Taconite", in _A Decade of Computers in the Mineral Industry_, 1969.

3.4.9 Methods used by Bennett et al[9]

Sensitivity and probabilistic analysis, the latter based on the Forsythe-Peiker AMAX model, is employed in the Bennett mine valuation model in FORTRAN. Although the model operates on completely user-specified cost and operating/technical data, it differs in two respects from other models thus far reviewed in this section. Firstly, the mining and milling cost breakdowns for both operating and capital costs are fairly detailed, permitting model application at a feasibility study level of project development. Furthermore, costs are calculated (outside the model) for different plant sizes, and mining and processing systems. The model is used in the analysis to choose the best mining system, milling process, and production rate at different costs, grades, recoveries, and prices, using discounted cash flow as the decision criteria. Thus, the model can be used to "optimize" between the limited alternatives through comparing runs of the program under the various alternatives and conditions. The approach is an application of sensitivity analysis. Probabilistic rate of return calculations are generated as output.

The authors note that relationships important in a more detailed analysis, for example grade-recovery functions, are not treated in the program. The program source code is included.

3.4.10 Ontario's Macroeconomic Model of the Mining Industry[26,27]

A different approach to modelling is used by Anders et al in their analysis of policy effects on Ontario's mining industry. They define several economic relationships relevant to the industry, and attempt to derive a model for the industry as a whole based on these relationships and their effects as reflected in historical data. Such a model quantifies the influence of policy changes on mineral industry investment. The investigation of the uses and relationships of such macromodels to MINSIM may be an interesting topic for future research.

3.5 Other Models and Model Segments

It is possible, at this point in the literature review, to construct a framework for mine models. This framework is evident in the organization of the Kemmerer Coal modelling project into 4 phases (see page 28). These phases may be said to correspond to four basic modelling steps:

- I Ore Reserve Calculation
- II Pit Design and Location
- III Production Scheduling
- IV Financial Analysis, consisting of:
  - a) cost estimation
  - b) financial analysis.

The ERDA approach uses a separate macro or micromodel to perform steps I, II, III, and IVa, and develops a Cash Flow Anlaysis Model which performs step IVb. Michelson et al use their Quality Model to accomplish step I. Their DCF Cost Model (step IVa) is used in the Economic Availability Model to perform step IVb. Since the evaluation is conducted over an entire region, steps II and III are omitted.

There are significant interrelationships between the steps. For example, mining costs determine cutoff grades and thus affect ore reserve calculations and pit design; pit design affects and constrains production scheduling; and production scheduling affects cost. Most of the models reviewed thus far either attempt to treat the system as a dynamic whole as in the Helliwell-Bradley model's determination of cutoff grade and ore reserve tonnage or, more commonly, ignore the interrelationships of the system by fixing all important operating/technical and cost parameters outside the model.

The following sections discuss the relevance of each of the above-listed model components to the development of MINSIM.

3.5.1 Ore Reserve Calculations and Models

There are several methods, both manual and computerized, for calculating ore reserves and grades from geostatistical data. Since it is the purpose of MINSIM to simulate the operation of specific B.C. mines, it is desirable to base the model as closely as possible upon data and calculations made by each company as to ore reserves. It is not feasible for MINSIM to perform the actual ore reserve, stripping ratio, and cutoff grade calculations from base data because 1) the data are not generally available to MMPR at the required level of detail, and 2) even if the data were available, the variety of estimation methods and statistical treatments available would make duplication of a mining company's results almost impossible. Also, modelling of one company's calculation "system" would not be applicable to another mine's system, thus destroying the purpose of one "general" B.C. mine model.

Data on ore reserves, grades, etc. will therefore have to be collected from available industry, independent engineering, trade literature, and other sources. A study of the availability, detail, and accuracy of such data is of major importance in Stage II of MINSIM, since it will determine to some extent the detail and the operational accuracy of MINSIM.

3.5.2 Pit Design and Location

Incorporation of a pit design module in MINSIM is subject to the same arguments discussed above, namely the diversity of methods employed, and the lack of a detailed data base, such as ore grade and tonnage information which would be the output of an Ore Reserve module.

3.5.3 Production Scheduling

This term may be used to refer to the development of a detailed mining plan at any level, from the day-to-day scheduling and simulation of truck haulage to the yearly operating schedules of a mine. At some point, this step involves the calculation of equipment requirements and production rates. Clearly, this information cannot be derived on a detailed basis without reference to ore reserves and mining blocks. However, it is possible to develop a schedule based on given (input) data of a more general nature. For example, information on the planned ore tonnage to be mined each year, and approximations regarding rock expansion coefficients, ore:waste ratios, and stripping ratios will permit equipment assignments to be made as a basis for cost calculations.

3.5.4 Financial Analysis

1. Cost Estimation

   a) Capital Costs

      The American Association of Cost Engineers suggests five types of procedures for new project capital cost estimating*

* after Mular (1978)

i) Order-of-magnitude estimate based on previous cost data. It is a ratio estimate of more than ± 30 percent probable accuracy. The level of aggregation generally does not permit adjustment of the estimate by additional component cost information which may be available. Also, new mines are generally more expensive due to increasing exploration and development costs in more remote areas, the trend towards larger plant scales, and the mining of lower grade marginal deposits.

ii) Factored estimate based on major equipment costs with a probable accuracy of ±30 per cent.

iii) Budget authorization estimate (preliminary estimate) based on sufficient data to permit budgeting. Probable accuracy is ±20 per cent.

iv) Definitive or projeot control estimate bases on almost complete data (no specifications or complete drawings). Probable accuracy is ±10 per cent.

v) Detailed or contractor's estimate based on complete engineering drawings, specifications, and site surveys. Probable accuracy is ±5 per cent.

Capital cost information on the level of iii) or iv) may be available in the form of project feasibility studies. For operating mines, total capital costs may be known. However, for the purposes of calculating depreciation, it is desirable to have some estimate of capital costs on a component basis.

Derivation of mining equipment costs does not present a serious problem, as equipment item costs and units of equipment and spares required is all the information that is needed. Jarpa[68] (1973) suggests the following sources of equipment cost data (in decreasing order of accuracy and reliability):

i) recent manufacturer quotes;
ii) company records from a previous job;
iii) trade literature
iv) professional societies;
v) textbooks.

Processing plant costs, however, are not so easily derived, as they involve charges for construction and installation, piping, electricity, etc. Mular[72] (1978) suggests four methods of deriving fixed capital cost estimates:

i) Six-tenths rule, whereby the cost of a given plant is derived from the relationship:

$$\frac{C_1}{C_2} = \left(\frac{Q_1}{Q_2}\right)^e \quad \text{and } Q_1 > Q_2, e=0.6$$

where C_1 is the unknown cost of the considered plant, Q_1 is its design capacity, and C_2 is the known cost of a plant of capacity Q_2. Alternatively, one may choose to derive the exponent, e, from B.C. mining data if such are available. This requires that one know the values of variables C_1, C_2, Q_1, and Q_2 in order to solve the equation for e.

ii) Plant Cost Ratio Method

This requires an estimate of the delivered cost of the process equipment which is used in the equation:

$$FCC = k\ (EC)$$

where FCC is the total fixed capital cost of the plant, EC is the delivered equipment cost, and k is an engineering cost constant for a given type of plant (solid vs. solid-fluid vs. liquid process plant).

iii) Equipment Cost Ratio Method

This method is similar to ii), except factors for each type of equipment are used:

i.e., $$FCC = \sum k_i \ EC_i$$

where k_i is the cost factor to be applied to EC_i, the equipment cost of equipment type i. The sum of these costs is the total fixed capital cost of the plant.

iv) Plant Component Cost Ratio Method

Using this method, the components of fixed capital cost are estimated as fractions of equipment cost:

eg.

ITEM	FRACTION OF EQUIPMENT COST
Equipment	1.00
Installation	.22
Piping	.05
Electrical	.20
Instrumentation	.06
	1.53

so FCC = 1.53 x EC

Note that methods ii), iii) and iv) require some form of plant flowsheet.

Johnson and Peters[69] (1969) use method iv) in their "Computer Program for Calculating Capital and Operating Costs". They present a framework for economic evaluation of a metallurgical process consisting of these steps:

1. Make material and heat balances
2. design plant
3. size and cost equipment
4. estimate raw materials, utilities, labour requirements
5. determine capital and operating costs
6. present results.

Steps 1 and 2 require the construction of a flowsheet. Figure 11 is a representation of the steps used in their FORTRAN program to calculate capital costs by the Plant Component Cost Ratio Method.

FIGURE 11

Johnson and Peters Capital Cost Estimation

A. Total Direct Cost - for each mill section

1. Updated Equipment Cost (UEC) = Equipment Cost x Marshall-Stevens Index*
2. Erection Labour (EL) = factor x UEC
3. Erected Cost (EC) = UEC + EL
4. Section Erected Costs (SEC) = $\sum$ EC
5. Piping, Instruments, etc. (PIC) = factor x SEC
6. Miscellaneous Equipment, Construction Costs (MEC) = factor x SEC
7. Total Direct Cost (TDC) = SEC + PIC + MEC

B. Field Indirect Cost - for each mill section

8. Field supervision, inspection, temporary construction, equipment rental, payroll overhead (RIC) = factor x TDC

C. Total Section Cost

9. Total Construction Cost (TCC) = FIC + TDC
10. Engineering, Administration, Overhead (EAO) = factor x TCC
11. Contingency Cost (CTG) = factor x (EAO + TCC)
12. Contractor's Fee (CNTR) = factor x (TCC + EAO + CTG)
13. Total Indirect Cost (TIC) = FIC + EAO + CTG + CNTR
14. Total Section Cost (TSC) = TDC + TIC

---

*Several capital cost indices such as the Marshall-Stevens Index are available in publications such as Mining Engineering.

Source: Johnson, P.W., and F.A. Peters, "A Computer Program for Calculating Capital and Operating Costs", U.S.B.M. Information Circular 8426, 1969.

Figure 11 (Cont'd)

D. 15. Calculate Steamplant Cost (STMCST) if appropriate (special program section)

E. Total Fixed Capital Cost

16. Capital Cost of Plant (CAP) = STMCST + $\sum$ SCT
17. Plant Facilities (PF) = factor x CAP
18. Plant Utilities (PU) = factor x CAP
19. Total Plant Cost (TPC) = CAP + PU + PF
20. Interest Cost during construction (INT) = IRATE x (TPC + LAND)

    where IRATE = effective borrowing rate over construction period

    LAND = cost of unimproved real estate

21. Total Fixed Capital Cost (TFCC) = TPC + INT + LAND

F. 22. Working Capital Investment (WCI)

= raw materials and supplies inventory for W months

\+ product and work-in-process inventory for X months

\+ accounts receivable for product sold, based on operating cost for Y months

\+ available cash for operating expenses, based on total direct operating cost for Z months.

G. 23. Value of Recoverable Chemicals (VCHEM) at shutdown

H. 24. Total Capital Cost TOTCAP = TFCC + WCI + VCHEM

b) Operating Costs

Some methods for operating cost estimation were presented in Section 3.3. The simplest estimates are merely per ton unit costs exogenously determined at various cost breakdown levels. The prime disadvantage here is that any operating economics of scale must be accounted for outside the model. Also, the effects of production interruptions cannot be modelled. All costs in such a unit cost estimate are assumed 100% variable with production rate.

Johnson and Peters[69] (1969) classify operating costs as direct, indirect, and fixed. Again, the factoring method is used. The procedure is outlined in Figure 12. The system is flexible with respect to number of shifts, work days per week, and operating days per year, thus allowing for modelling of production interruptions.

FIGURE 12

Johnson and Peters Operating Cost Estimation

A. Direct Costs

1. Direct Labour (DL) = equipment manning requirements x wages

2. Supervision Labour (SL) = factor x DL

3. Plant Maintenance (PM) = sum of :

   a) Equipment Maintenance = (factor x equipment cost), all items
   b) maintenance for buildings, electrical, piping, etc.
      = factors for each x severity of service factor x
        type of service factor x initial cost
   c) maintenance of plant facilities and utilities
      = 1% of their cost
   d) steamplant maintenance
      = 3% of cost (natural gas or oil)
      = 4% of cost (coal)

4. Plant Maintenance Labour (PML) = factor x PM

5. Plant Maintenance Labour Supervision (PMLS) = factor x PML

6. Payroll Overhead (POH) = factor x (DL + SL + PML + PMLS)

7. Operating Supplies (OS) = factor x PM

8. Royalty Charges (RC) - depends on tax environment

9. Direct Cost (DC) = DL + SL + PM + PML + PMLS + POH + OS + RC
   + raw materials + utilities.

B. Indirect Costs (IC) (includes: control labs, accounting, plant safety, plant administration, marketing, company overhead) = factor x (PM + DL).

C. Fixed Costs (FC) = sum of:

   1. Property Taxes (PTAX) = factor x Total Plant Cost (TPC, see Figure 12).
   2. Insurance (INS) = factor x TPC
   3. Depreciation (DEPR), straight-line method

$$= \frac{\text{(TFCC - LAND)}}{\text{Plant Depreciation Life}}$$

Source: Johnson and Peters (1969), op. cit.

FIGURE 12 (Cont'd)

D. By-products (BYPR) - treat as a credit against operating costs

E. Total Operating Costs = DC + IC + FC - BYPR

2. Financial Analysis

Every valuation model, whether mine-specific or general (eg. MPS-F[75] and FIPAC[76]), employs some form of financial analysis. The basis of the financial analysis is the development of one or more of the following financial statements:

1) Income (Profit and Loss) Statement
2) Sources and Uses of Funds Statement
3) Balance Sheet

The income statement accounts are almost always developed on at least a year-by-year basis, whether or not the actual statement appears as program output. The non-cash accounts, such as depreciation and depletion, are then added back into the net income to arrive at net cash inflow. Net cash flows are calculated by subtracting the annual capital expenditures from the net cash inflow. The net cash flow is the basis for most of the financial measurements (NPV, DCFROR, discounted payback period) commonly developed by valuation models, and is sometimes detailed in output in the form of a cash flow or funds flow statement.

The so-called "stock" accounts, consisting of assets, liabilities, and owners' equity items, comprise and balance sheet. This statement is not always included in financial valuation models, but can be useful in measuring the effects of the mining venture in terms of certain financial ratios. The fixed asset accounts are usually already developed in the model for use in calculating depreciation for tax purposes.

In models which provide for various forms of financing, long term debt and owner's equity accounts are also already calculated.

3.6 Public Policy Questions

In the course of Stage I research, several public policy issues in mining were investigated. The options available to the public sector for dealing with these issues is of importance to MINSIM. The model must provide suitable structure and sufficient flexibility to test the alternatives available. The major areas of public policy concern with respect to MINSIM are outlined below.

3.6.1 Taxes and Royalties

It is of course necessary to model accurately the present Canadian and B.C. mining tax systems applicable to operating and potential B.C. mines. Systems for mines both with and without other sources of income should be modelled. In addition, other tax and royalty options should be considered. There are two reasons for this. Firstly, the performance of B.C. mines under current and proposed systems could be compared. Secondly, the performance and adequacy of the current system could be compared with other areas of mineral potential outside the province in order to assess the relative investment climate and operating conditions in those areas.

Flexibility in tax options means far more than being able to vary mining tax rates. The calculations of income upon which taxes and royalties may be based, and the deductions made eligible for taxable income (eg. processing allowances, depreciation rates and bases, depletion allowances) can vary widely. Just what options and systems may be desirable in MINSIM will be determined in subsequent stages of the project, and should be a topic of ongoing consideration in future MINSIM applications.

3.6.2 Environmental, Safety, and Other Regulations

Government requirements and regulations may be considered to have an effect on mine operations in one or more of the following ways:

1. changing the direct investment and/or operating costs of the operation;
2. changing the indirect or overhead costs of the operation;
3. changing the time schedule for development, expansion or closure of the mine;
4. changing the operating characteristics (eg. tonnage, average or cutoff grade, production rate) of the mine;
5. eliminating certain options in mine operation or development.

In some cases, regulation-associated costs may be built in as components of other costs. However, it may be desirable to give explicit recognition to some of these costs (eg. the effective cost to a mine of posting a performance bond to cover reclamation requirements).

3.6.3 Government Grants, Loans, and Subsidies

Injection of public capital into private projects will generally change the financial picture of a mining operation from the viewpoint of governments (in the form of net receivable revenues), society (in a cost-benefit sense), and the owners and operators of the mine. The form of financial assistance provided is important with respect to cost to the mine of the funds provided, the time horizon of the fund disbursements, and the financial and tax status of the funds. Contribution of government funds may also change the discount rate one wishes to employ in calculating the discounted value of cash flows.

Government capital can be supplied or invested either directly in the mining operation or in connection with the supply, maintenance, and operation of associated townsite and transportation infrastructure and services. Direct government investment in the mining industry has not been important in the past in B.C., and will not be modelled explicitly in MINSIM. The use of government funds in infrastructure is not uncommon. However, it is the role of MINSIM to provide a model to <u>assist</u> in economic cost-benefit analyses assessing the desirability of such investments. MINSIM will be capable of examining the public and private cash flow ramifications of such government funding. Such a function can be accomplished within the framework of a private valuation model.

3.6.4 Social Valuation Concepts

As noted in the Helliwell-Bradley model discussion, it is possible to derive several measures of the social value and efficiency of a mine. However, the main purpose of MINSIM lies in measuring the effects of various policy factors on the operation and finances of the private sector mining operation. The information necessary to perform cost-benefit analyses and other social evaluations can be generated by such a model, but the various assumption and complex questions arising in a cost-benefit evaluation will not be dealt with in MINSIM. This means that, while the information will be available for use in such studies, the manner in which they are used and the assemptions behind the studies remain within the province of the analyst and specific to the study, rather than in a model.

3.7 Mine Financing

The way in which a mine is financed can affect the value of the mine to the private owner/developer by:

1. changing the actual interest and other financing charges payable;
2. changing the timing of financial charges and payments;
3. changing the "hurdle rate" (cost of capital) used to calculate the NPV of the mine;
4. changing the tax status of the funds, and thus the taxable income of the mine;
5. changing the total private fund requirements of the project, as in the case of government financial aid;
6. changing the debt/equity ratio, and thus the return on equity measurement.

For these reasons, there should be provision within the model for adequate consideration of mine financing methods.

The effects of debt/equity ratio changes and the importance of being able to specify this ratio within the model was reviewed in Section 3.3.3. There are other forms of mine financing that can change mine valuation through the above mechanisms. They are briefly reviewed below.

3.7.1 Production Payments

These relate to loans which are paid off in installments determined with reference to some measure of production. Thus, interest charges and reductions in principal do not generally occur at fixed time intervals, but are dependent on the mine's production rate.

3.7.2 Leasing

Ordinarily, short term lease costs are treated as expenses. However, where leases are deemed to be financial transactions for tax purposes, as is the case in some long-term equipment leases, certain advantages are available. Each rental payment is construed to consist of interest expense and principal repayment. This interest expense is deductible. In some cases capital cost allowance is also deductible. The lessee thus gets the tax advantages of borrowing-to-purchase with off-balance sheet financing. More commonly, the lessor will choose to be the equipment owner, thus obtaining the CCA for himself, and passing on these savings to the lessee through reduced lease rates.

Timbrell[85] (1978) contrasts the pros and cons of leasing vs. debt in the pre-production and production periods. A lease is to be preferred in the pre-production period, since:

1. capital cost allowance reduce the resource allowance base, while pre-production expenses (ie. lease payments) do not;
2. the interest element of pre-production lease costs is a qualifying expenditure for earned depletion, whereas interest on debt is not.

On the other hand, after production starts, lease payments are considered operating expenses and therefore reduce the resource allowance base, whereas debt interest expense does not reduce that base. Also, lease costs of processing equipment in the production period are not qualifying expenditures for earned depletion, but purchase costs are.

3.7.3 After-Tax Financing

Financing through after-tax instruments such as income debentures permits payments to be made only from after-tax profits. This is advantageous in any industry where CCA and other tax deductions are initially very high, as in the case in the mining industry. In the case of income debentures, interest is treated as a dividend, being non-deductible for the payor and tax-free for the investor. The latter provision results in income debenture interest rates being only about one-half those of conventional debt. Tax revenue losses claimed by Revenue Canada have resulted in some proposed changes to the status of income debenture payments, but other instruments (eg. "retractable preference shares") are being developed which have similar effects.

3.7.4 Joint Ventures vs. Partnerships

In partnerships, each partner is bound to claim his proportionate share of claimable write-offs after the partnership claims all its useable tax write-offs. Joint ventures, however, permit each participant to claim CCA's separately. The common use of joint ventures in B.C. accents their importance in a MINSIM model.

The above is presented not as a review of modern mine financing methods, but as as illustration of the importance of mine financing in a mine valuation model with respect to 1) accurately accomodating such financing methods in the model structure, and 2) recognizing and providing for such financing methods when examining a given mine case using the MINSIM model.

IV. A MINSIM FRAMEWORK

The preceding section has outlined many of the key issues in mine modelling, and described approaches and techniques commonly employed in each area. We are now in a position to consider these issues with respect to the MINSIM model, and to make some preliminary recommendations in the form of a suggested model framework.

4.1 Viewpoint

As discussed in Section 3.6, it is possible to view a mining operation from the perspectives of several different concerned parties - the owner(s) and/or operator(s), the government, and society in general. The owners are concerned mainly with the private valuation of the mine - ie. the conventional profit and loss statement, net cash flows, and private valuation measures such as NPV and DCFROR. The government may be interested in private valuation as well as concepts such as economic rent to the various governments, and operational efficiency measures (eg. the true economic cost of copper extraction at various mines). Society in general is most concerned with the net social value of the mine in a cost benefit sense. This may, of course, be one of government's prime interests also.

The main purpose of MINSIM is to simulate as accurately as possible the financial position of various B.C. mines. Although it can and should be used as an information source for cost-benefit analysis, the variety of assumptions and allowances for externalities necessary in a social benefit-cost (SBC) analysis make the mine model an inappropriate tool for performing the analysis. Such a function would be too inflexible for use in benefit-cost analysis, and would make the model excessively complex and cumbersome for other uses. The definitions, assumptions, and allowances necessary in and specific to a given social benefit-cost analysis are thus left in the province of the analysis itself.

MINSIM should, however, develop data on a private valuation basis in sufficient detail for, and in a format useful as input to, social benefit-cost by inclusion of full government rent calculation and output. This is easily incorporated within a private valuation framework.

As discussed in Section 3.7, mine financing can affect the economic valuation of a mine. It is therefore desirable that MINSIM be able to measure both the value of the mine on a 100% equity - financed basis as well as to model accurately the mine valuation under the alternative financial structures. This means not only the provision for modelling a given debt/equity balance, but also the ability to model joint ventures and other financing forms. Such measures will provide 1) a value for the mine independent of financing, 2) a measure of the effects of alternative financing, and 3) value of the mine to each financial participant.

4.2 Simulation Approach

The main choice in simulation techniques to employ in MINSIM is between the deterministic and probabilistic approaches. Both can be used in comparative statics and sensitivity analysis. Only the probabilistic approach, however, yields a measure of financial risk of the mine project. It also uses more information regarding input variables.

Three factors influence and determine the choice of simulation technique:

1. relative costs of two systems in terms of:

    a) model development and programming (initial) costs;
    b) computer run simulation costs.

2. the availability and accuracy of probabilistic input data;

3. the appropriateness of a probabilistic approach in light of MINSIM functions, uses, and objectives.

No attempt has been made in Stage I research to examine the first two factors. Some preliminary comments may be made concerning the third factor - MINSIM requirements.

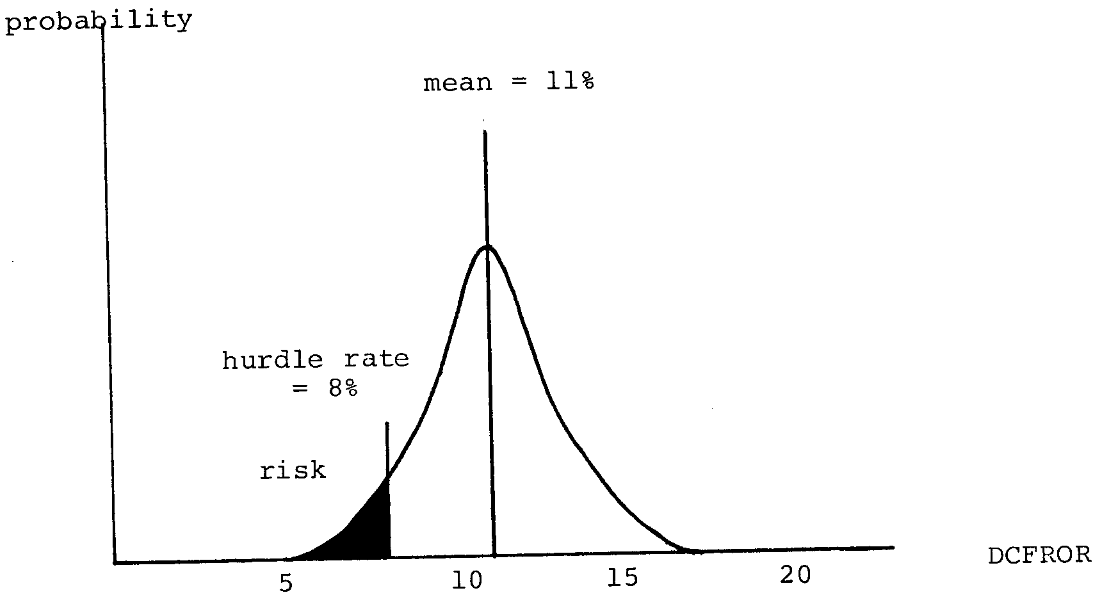
Many of the policy variables, for example tax rates, which one may wish to test via MINSIM are of a deterministic nature. They have little or no associated uncertainty. While their adjustment in value may change the mean of an output measure (eg. DCFROR), it will probably not change the nature of the measure's distribution. The effects of such a change will therefore be unambiguous as measured by either simulation technique. The effects of a policy change on a project's <u>risk</u>, however, can only be measured by the probabilistic approach (see Figures 13 a and b). In addition, the modelling of any mining operator decision-making capability (see Section 4.4.4), such as incorporation of alternative mining systems, may change certain input variable distributions dramatically, thus changing the project risk distribution (see Figures 14 a and b).

The choice between techniques is therefore a complex one, and will be examined further in Stage II.

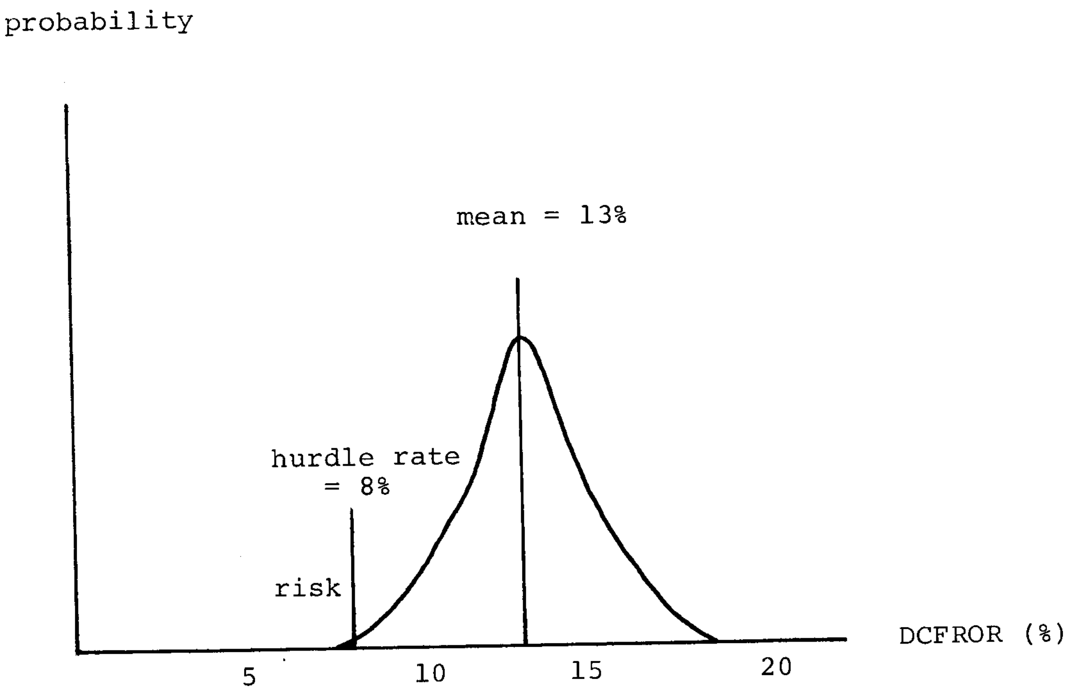
Sensitivity analysis and comparative statics (an application of the former technique) will be incorporated in MINSIM to provide analysis of model input variables and the influence of changes in these parameters on output measures. This feature can be constructed in such a way as to permit testing of a case under different conditions in one computer run.

FIGURE 13

Effects of Tax Rates on DCFROR



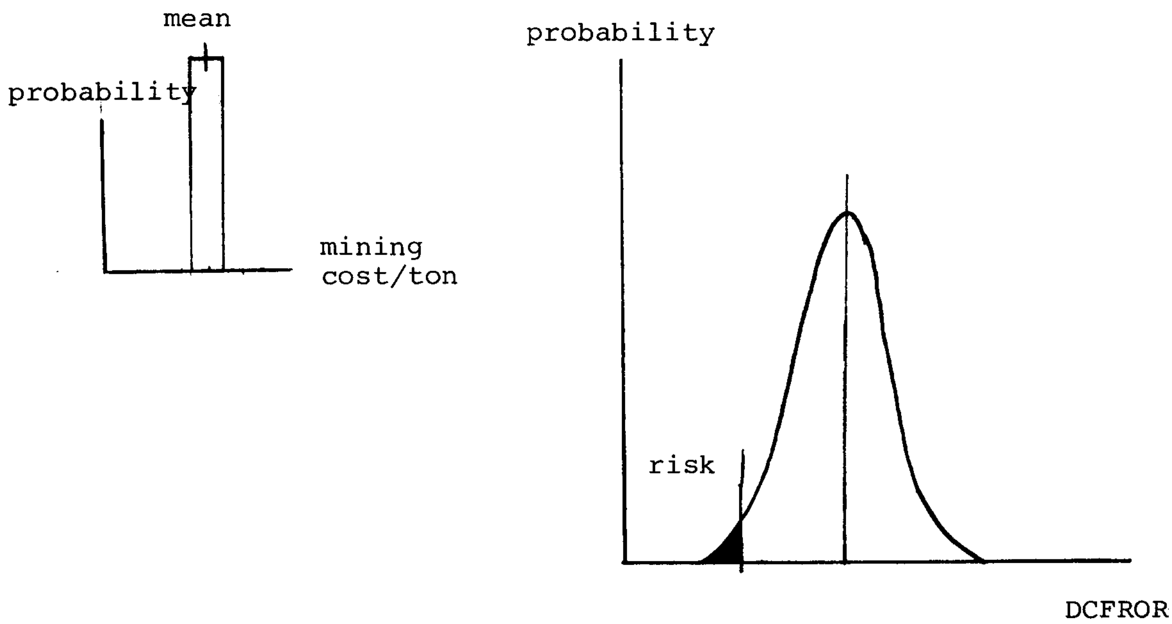
a) Mineral Resources Tax rate = 17.5%



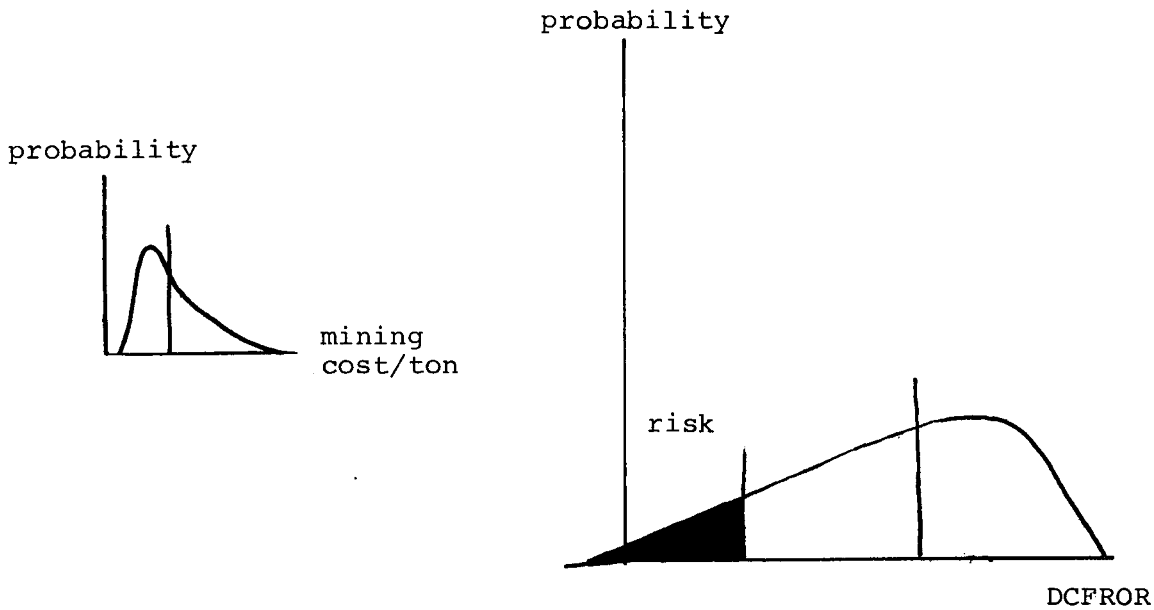
b) Mineral Resources Tax rate = 10%

FIGURE 14

Effects of Operating Cost on DCFROR



a) DCFROR With Mining System A.



b) DCFROR With Mining System B.

4.3 Scope

"Scope" herein refers to the range of mine planning activities that may be considered in mine modelling. As outlined in Section 3.5, the planning/valuation process can be classified into four interdependent steps:

- I Ore Reserve Calculation and Models
- II Pit Design and Location
- III Production Scheduling
- IV Financial Analysis

For reasons discussed previously (Section 3.5), it is not deemed appropriate to include the first two steps in a general B.C. mines model. However, it is important to structure the model in such a was that it will be able to accept information and calculations that may become available in these areas for the purpose of accurately modelling production schedules. The capability should therefore exist within the model to accept ore cutoff grades, ore tonnages, ore:waste ratios and stripping ratios at appropriate time intervals for use in developing average ore grades, and equipment schedules and requirements. Modules that may be developed in the future for performing steps I and II on a mine-specific basis can in this way be used to generate input for MINSIM without decreasing the model's flexibility and general applicability.

4.4 Operational Detail

4.4.1 Cost Estimation and Production Scheduling

The choices of what structures should be adopted for production scheduling and cost estimation modules in MINSIM are interrelated questions. For example, if cost data and information on equipment numbers and spares are available, cost estimates may be built up by assignment of costs to equipment items as determined by the production schedule. Labour costs can be similarly derived by assigning wage rates to labour hours as specified by manning requirements given in production schedule input data. On the other hand, if cost estimates are only available on a per unit ton aggregate basis, the production schedule may merely consist of an annual production rate figure. Obviously, the detail of available information will vary somewhat from mine to mine. It will therefore be necessary to accomodate various levels of detail. What range of levels are modelled will depend on the type and detail of data available.

Certain expenses are particularly amenable to treatment by factoring (ie. expression as a percentage of some other account):

FACTORED ACCOUNTS	"BASIS" ACCOUNTS
supervision labour	direct labour expense
payroll overhead	total labour expense
sales, administration	total cost of product sold
plant overhead	plant capital cost and/or plant operating cost
maintenance	equipment cost
operating supplies	maintenance expense

In some cases, it may be possible to build up or derive these figures directly and project them into the future. The factoring method is an alternative when this is not possible. Its usefulness depends upon the behavior and stability of cost relationships over time.

4.4.2 Revenue Calculations

Revenue determination can not be approached on the fairly detailed level demonstrated by J.K. Wright's model. The ability to simulate smelter and sales contracts in MINSIM is restricted by contract confidentiality and variety. J.K. Wright* suggests that sufficiently accurate revenue figures can be generated without the use of smelter contract information.

4.4.3 Balance Sheet Accounting

Current asset and liability accounts can be valued, in some cases, from the existing entries in an operating mine's balance sheet, and either held constant, or inflated by some inflation factor for future periods. This information may not be available for consolidated companies and future mines. Furthermore, projections on the above basis can be misleading. Most current accounts can be derived by factoring other accounts:

CURRENT ACCOUNTS	BASIS ACCOUNTS
cash	operating expenses
accounts receivable	sales for W months
product inventory	cost of products produced in X months plus work-in-progress value
material and supplies inventory	value of purchases over Y months
accounts payable	value of purchases over Z months

The maintenance of a balanced system of accounts can be achieved through use of short term debt as a "plug" figure in the cash flow statement. The usefulness of such a feature will depend on the magnitude of its effects on the financial operations of a company, and the level of

*Meeting of Friday, November 3, 1978 in Vancouver disaggregation possible in the other cash flow accounts.

Fixed assets must be accounted for in at least enough detail to permit separation of various asset classes for the purposes of depreciation calculations. At a minimum, this means the separation of mill assets, mining assets, exploration and development expenditures, and land costs. Further detail again depends on the method cost estimation used. Item-by-item cost accounting permits the scheduling of replacement expenditures on a detailed basis, using estimates of real machinery life. At this level of detail, various equipment purchasing plans and order delivery times can be modelled. Early-year production build-ups can be modelled from equipment purchase patterns in these years.

Long-term debt and equity accounts can be determined from specified debt/equity ratios and capital expenditure schedules. Debt principal and interest repayment schedules should be developed at a level of detail commensurate with other model accounts. All debt should expire on or before the date of mine closure. Provision for so-called "off-balance sheet" financing (eg. leasing) should be included as notes on the balance sheet when assets leased are to be capitalized. As noted in Section 3.7, various forms of financing entail different time schedules and expenses. They should be accounted for separately.

4.4.4 Mine Management Operating Decisions

Most of the models reviewed in this study have no ability to consider mine management decisions during the operating life of the mine. Such decisions could include:

1. permanent or temporary mine closure in the event of marginal (variable) costs exceeding marginal revenues;
2. changes in stripping ratios;
3. changes in cutoff grade or order of mining;
4. changes in operating procedures and processes.

In an actual mining situation, such measures may be taken from time to time under changing economic conditions. The ability to model such changes will depend on the information base of the model. For example, if variable operating costs can be segregated, and the cutoff grade determined in the modelling process (either within the model or exogenously by the model user) and, further, if some information on grades and tonnages of ore blocks is available, it would be possible to develop criteria for cutoff grade adjustments and/or production cutbacks and mine closures. The evaluation of incorporating different mining or milling procedures would also be possible. The effects of such decisions may be critical when testing various policy alternatives. These criteria are generally straight forward, and should be modelled as options which could be employed in cases where the above information is available.

4.4.5 Public Policy Modules

Alternatives for modelling various public policies are briefly reviewed in Section 3.6. MINSIM should be able to consider:

1. different tax rates;
2. different definitions of taxable income, and various tax deduction items and rates;
3. various tax structures (eg. ad valorem, royalties);
4. various other charges (eg. land lease rentals, costs of performance bonds, reclamation and safety costs, etc.);
5. various credits in the form of government grants, subsidies, and loans;
6. tax credits;

The present Canadian and B.C. tax structures and rates, various proposed and possible options, and conditions and regulations in other geographical regions of interest could be modelled. Stage II will attempt to identify possible options in this area. A modular approach to tax and regulations modelling would permit additions to the model's public policy analysis capability in the future.

4.4.6 Output Measures

The basic outputs in a financial valuation model are the cash flows, NPV, and DCFROR. Other useful outputs include: income (profit or loss) statements; balance sheets; a summary of government revenues generated from, and expenditures on the mine; physical reserve and production schedules; labour requirements and wage schedules; and townsite and transportation infrastructure breakdowns by financial contributors (private vs. government). Project finances for each participating firm should reflect investment, operating cost, profit, and tax deduction sharing provisions. Graphing capability for cash flows might be useful.

V. GUIDELINES FOR STAGE II RESEARCH

Stage I research has defined a general modelling framework and identified several alternative modelling options and approaches for consideration in a MINSIM model. Initial emphasis in Stage II will be towards soliciting further suggestions in both approach and methodology from parties in the mining industry, the public sector (within and outside British Columbia), and the academic community, and collecting data upon which these options can be evaluated. A general outline of plans for Stage II research is shown diagrammatically in Figure 15. The evaluation phase consists of choosing the appropriate methodologies and identifying key model variables and equations to be incorporated in the final phase of Stage II - the construction of a preliminary MINSIM flowchart.

Most of the main areas of data collection and methodological research outlined in Figure 15 have been discussed to some extent in this paper. Further information, suggestions, and comments will be solicited in these areas as detailed below:

Simulation Costs

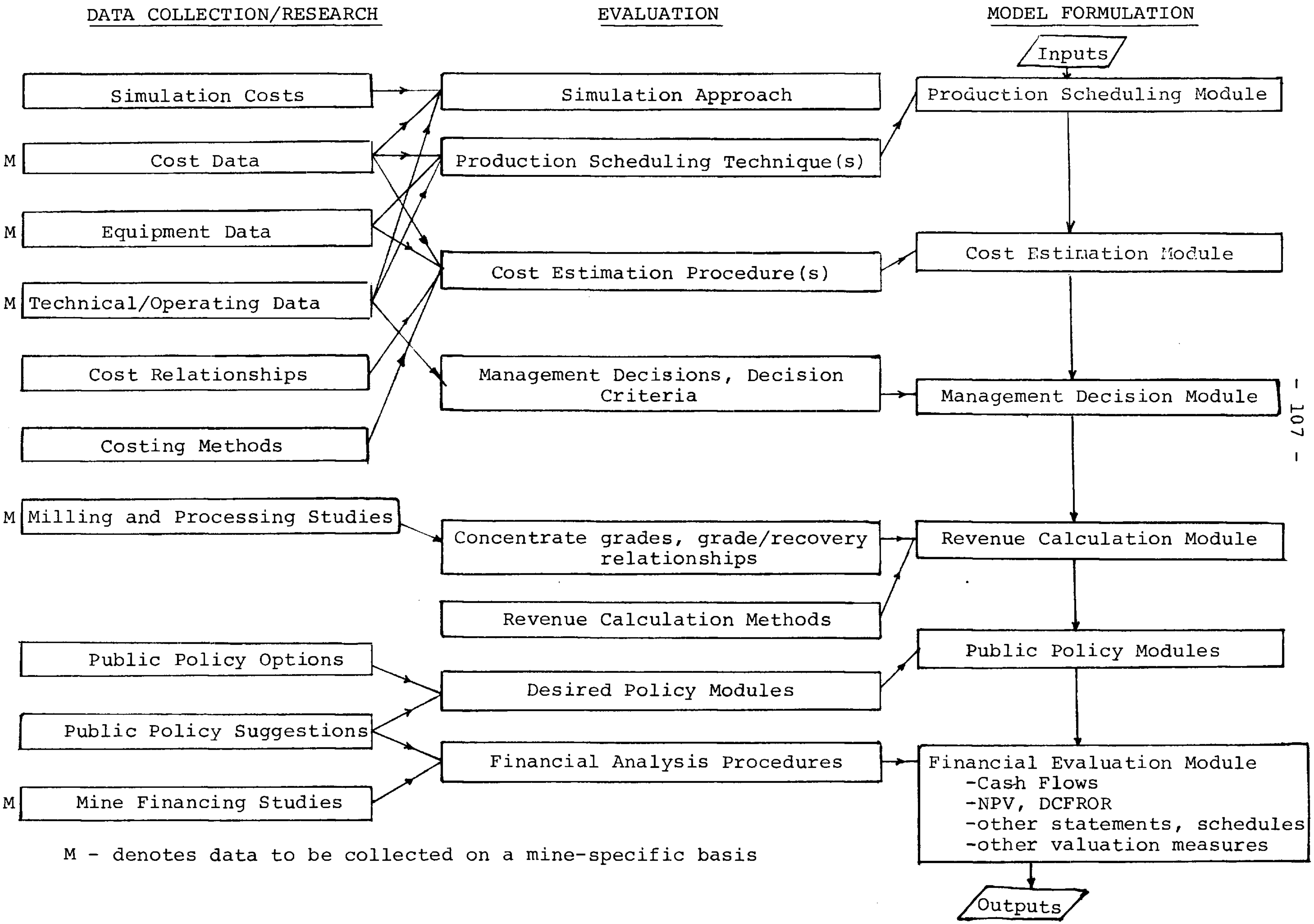
- estimation of the relative costs of probabilistic vs. deterministic approaches with respect to:
  - a) programming (initial) cost;
  - b) computer run (ongoing) cost.

Cost Data

- identification of useful data sources.
- documentation of cost detail and breakdown.
- identification of major cost centres, criteria for choice of cost centres.
- availability and cost of probabilistic cost data.

FIGURE 15

General Plan for Stage II Research



M - denotes data to be collected on a mine-specific basis

Equipment Data

- type and detail of information available on mining and milling equipment, especially number of units, availability, manning requirements, maintenance requirements, etc.

Technical/Operating Data

- information sources and documentation of data detail with respect to total ore reserves, ore block grades, stripping ratios, waste:ore ratios, order of mining information.

Cost Relationships

- investigation of the stability of some cost relationships to other costs as a basis for developing cost factors (see Section 3.5.4).

Costing Methods

- additional research into methods of capital and operating cost calculation.
- identification of relevant cost inflators (eg. Marshall - Stevens Index).

Milling and Processing Studies

- investigation of ore grade:recovery relationships and concentrate grades produced in various processes.
- usage of utilities and water
- tax classification of various mill assets.

Public Policy Options

- construction and modelling of the present tax and regulation environment faced by B.C. mines.
- investigation of tax and regulation systems of interest in other mining jurisdictions.

Public Policy Suggestions

- input from the mining industry, other government agencies within and outside British Columbia, and academics regarding possible areas of public policy which may be tested.

Mine Financing Studies

- identification and description of current and potential forms of financing that may be used in the B.C. mining industry.

A continuation of Stage I research into available mine models and their capabilities will be conducted in Stage II, with emphasis on investigating several private and proprietary metal mine models used by the mining industry.

The above information will be used to evaluate the options and alternatives (many of which have been presented in this report) for use in MINSIM. A preliminary MINSIM flowchart will be constructed in Stage II incorporating the chosen options, features, and techniques.

APPENDIX A

List of MINSIM Personal Contacts

Name	Company/Institute	Subject
Angel, A.	B.C. Hydro, Vancouver	-CROPS system specification for Hat Creek Coal mine planning.
Banfeld, Dr. A.F.	Mintech Inc., Tuscon, Arizona	-general computer mine modelling.
Boulay, R.A.	Bank of Montreal	-mining project evaluation system and APL model.
Bradley, P.	U.B.C. Dept. of Economics, Vancouver	-computer mine modelling,in particular mine model source code and assistance in its interpretation. Information on forthcoming program revisions.
Cash, P.	Wright Engineers Ltd., Vancouver	-Wright Engineers evaluation model of operating and capital costs.
Draffin, Cyril	Technical Projects Officer U.S. Dept. of Energy, Washington	-ERDA coal mine model documentation and user manuals.
Electric Power Research Institute, California		-bibliography of EPRI publications.
Evans, J.B.	U.B.C., Mineral Engineering Department	-literature sources on mine modelling
Halkett, P.	Government of Saskatchewan Executive Council	-Saskatchewan Uranium Royalty evaluation system (APL model).
Handelsman, S.	B.C. Hydro, Vancouver	-consultation on mine modelling and assistance in establishing other contacts and sources of information.
Helliwell, J.F.	U.B.C. Dept. of Economics, Vancouver	-publications on the use of the Helliwell-Bradley model in B.C. copper mine analyses.

APPENDIX A (Cont'd)

Name	Company/Institute	Subject
Henderson, J.	U.B.C. Science Library, Vancouver	-computer literature search on INSPEC bibliographic data base.
Kim, Y.C.	Dept. of Mining and Geological Engineering, University of Arizona	-access to Kemmerer coal model and associated publications, suggestions on other sources and contacts, assistance in model interpretation and model building in general.
Parker, W.M.	Dataplotting Services Ltd., Toronto	-information on services in financial modelling and graphing capabilities.
Power, Michael	Noranda Exploration Company Limited, Toronto	-Noranda Mine model (MAC model).
Sanford, R.L.	Dept. of Mining Engineering, University of Wisconsin-Platteville	-information regarding his forthcoming director, public-domain references extracted from the directory.
Schottler, G.	U.S.B.M. Technical Projects Officer, Denver	-information on publication of and access to Sanford's directory.
Stevenson, W.	W. Stevenson Engineering Ltd., Vancouver	-discussions on B.C. Chamber of Commerce/ interests in MINSIM development and use.
Wright, J.K.	Wright Engineers Ltd., Vancouver	-Wright Engineers evaluation model and Quick Capital Cost method.

APPENDIX B

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APPENDIX C
PHASE I REPORTS

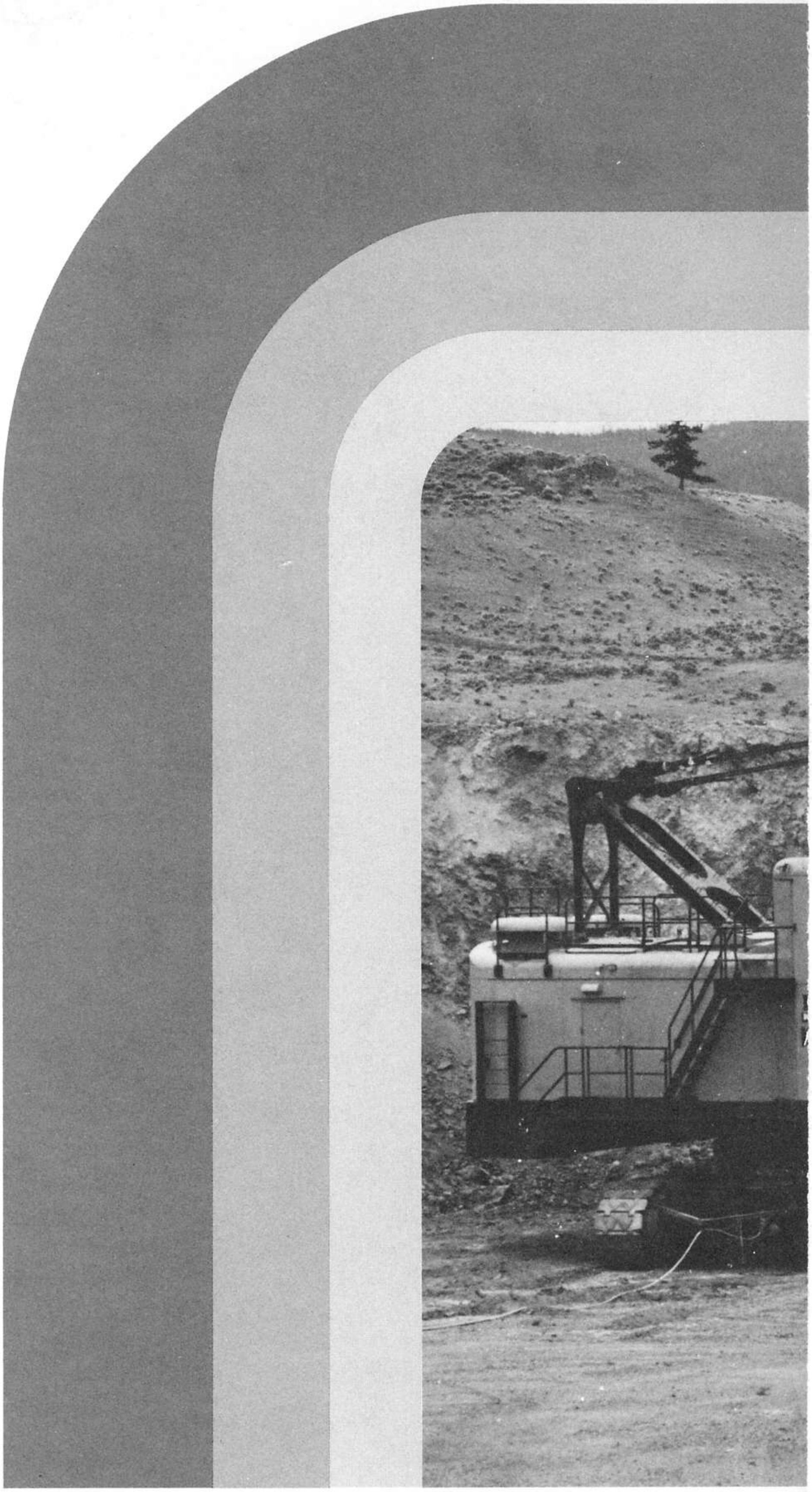
Economics of Large-Scale Surface Coal Mining Using Simulation Models

Volume No.	
1	Introduction, Summary, Conclusions, and Recommendations for Research. Summary of Phase I Results (31 pages, FE-1520-1)
2	Characterization of Coal Deposits for Large-Scale Surface Mining. Delineates strippable coal resource regions of the U.S. and describes their physiography, surficial deposits, soils, structural geology, general stratigraphy, and coal stratigraphy (346 pages, FE-1520-2)
3	Surface Coal Mining Methods and Equipment. Describes mining methods and equipment used in large-scale surface coal mining (109 pages, FE-1520-3)
4	Large-Scale Coal Processing for Coal Conversion. Discusses coal preparation plant design related to producing feedstocks for coal conversion and describes hypothetical plants for three types of coal preparation (80 pages, FE-1520-4)
5	Survey of Socioeconomics, Financial Statistics, and Legal Aspects. Provides an overview of the socioeconomic, financial, and legal factors which affect surface coal mining (121 pages, FE-1520-5)
6	Computer Systems to Support Mine Planning. Describes the status of the simulation models and supporting data files at the end of Phase I (307 pages, FE-1520-6)

APPENDIX D
PHASE II FINAL REPORTS

Economics of Large-Scale Surface Coal Mining
Using Simulation Models

Volume No.	
	SUMMARY
1	Executive Summary (FE-1520-101)
	REGIONAL TEST CASES
2	Area Stripping with Draglines Using Illinois Basin Region Test Case (FE-1520-102)
3	Area Stripping with Draglines Using Four Corners Region Test Case (FE-1520-103)
4	Area Stripping with Draglines Using Fort Union Region Test Case (FE-1520-104)
5	Area Stripping with Draglines Using Texas Gulf Region Test Case (FE-1520-105)
6	Contour Stripping with Draglines Using Appalachia-Ohio Region Test Case (FE-1520-106)
7	Area Stripping with Shovels and Trucks Using Power River Region Test Case (FE-1520-107)
8	Mountain Top Removal Mining Using Appalachia-West Virginia Region Test Case (FE-1520-108)
9	Multiple Dipping Seam Mining Using Green River Region Test Case (FE-1520-109)
	USER'S MANUALS FOR COMPUTER MODELS
10	User's Manual for Area Dragline Macromodel (FE-1520-110)
11	User's Manual for Area Shovel Truck Macromodel (FE-1520-111)
12	User's Manual for Contour Stripping with Draglines Macromodel (FE-1520-112)
13	User's Manual for Cash Flow Analysis Model (FE-1520-113)
14	User's Manual for Dragline Stripping Micromodels (FE-1520-114)
15	User's Manual for Shovel Truck Mining Micromodels (FE-1520-115)
16	User's Manual for Nonstripping Mining Function Micromodels (FE-1520-116)



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