PRECONSTRUCTION FINANCIAL PLANNING
OF LARGE PROJECTS

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ABSTRACT

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The financial models developed in this thesis facilitate the execution of strategic financial planning during the early phases of the project life-cycle. Such early planning is essential to large capital intensive projects where misguided fund appropriations can be detrimental to, or in fact lead to the demise of, a corporation.

Although the importance of financial decision making during the early phases of a project is well recognized, little effort has been expended to date in providing realistic financial planning models. The Macro and Micro models of this thesis aid project profitability by providing means of testing sensitivity of financial performance measures to both controllable and uncontrollable project factors, and vice versa, for a given engineering design technology. The developed models are presented as both generic mathematical formulae and as computer programs with substantiated constraints.

The importance of escalation and financing costs are investigated at the project level through use of the Macro Models. In contrast, the activity level Micro Model, as a

first step, considers the interaction between resources and activity cost. Numerous parameter studies are employed to demonstrate model applications and to identify general trends.

A tradeoff exists between model usability and the degree of complexity entailed to capture realistic properties; the more complex the fewer appropriate applications. The degree of detail employed in the models will prove adequate for most, if not all, projects. However, using the generic framework provided, the models can easily be expanded upon or adjusted to meet the criteria of specific applications.

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CHAPTER 1

INTRODUCTION

Financial analysis of construction projects has long been known to be critical to the success of projects. However, very little in the way of formal tools has been implemented in this field pertaining to capital costs, escalation costs, financing costs and cost tradeoffs.

Although the models developed in this work are applicable to any size project they are more appropriate for implementation on large scale projects where "rules of thumb" will not suffice. Exposure to inflation and interest charges over the long duration of large projects can create significant additional costs to the project.

Three major factors have given rise to the need for large projects. First, complex or innovative technology requires vast supportive facilities. Secondly and thirdly, "economic and marketing conditions have simultaneously increased sales volumes and placed high returns on very large capacity projects" (2).

"A Report by the Major Projects Task Force on Major Capital Projects in Canada to the Year 2000" (42), June 1981, identified approximately $440 billion worth of major projects primarily in the sector of energy production and distribution and hydrocarbon processing as well as in the sectors of forest products, mining, primary metals production, manufacturing, transportation and defence. The Task Force in its conclusions recognized the "need for research, development and innovation in areas of need arising from the planning and construction of major Canadian Projects." This thesis responds to this need in the area of financial planning through development of mathematical and computer models of total project cost and activity planning.

1-1 LARGE PROJECTS TODAY

The prime objective of any private sector project is to obtain facilities that fulfill all desired objectives which include minimization of total capital cost, maximization of net present value and reliability. In today's environment, economy of scale dictates the use of larger and larger facilities for competitiveness. Yet investors have become more apprehensive about following this policy because of the present economic instability in the North American arena.

Throughout the world major capital investments have been planned, and are being made, in an attempt to meet countries requirements of national security of supply objectives. This has been particularly true with respect to energy as many nations realized their dependence on an unstable sector of the world during the 1974 OPEC oil embargo.

In June of 1981 the Major Projects Task Force (42) predicted that Canada was about to embark on one of the most significant and extended periods of heavy investment spending in its history. Investment in major capital projects, particularly in the natural resource sector, was expected to account for more than 20% of the total investment in capital projects, during the twenty year period to the year 2000.

In the one and a half years since the rather optimistic report of June 1981, by the Task Force, a fear of bigness has overcome Canadian business. In late April of 1982 both the Alsands ($13.1 billion) and the Cold Lake ($14 billion) tar sands projects, which were to have been the first in the series of major projects identified in the $440 billion estimate, were cancelled. In addition, the $40 billion Alaska Highway Natural Gas Pipeline through Canada to the lower forty-eight American States was postponed for at least two years. In this time of pervasive, deepening uncertainty about the future, hard-headed caution dictates protection of corporate safety with policies of diversification rather than commitment of billions of dollars to one giant project.

There are sound reasons for the present fear of mega projects. Inflation has been characterized by fast and unpredictable changes, FIG. 1-1. The Consumer Price Index is generally selected to monitor inflation, however, capital spending plans have their own special and even more unpredictable inflation rates based on the machinery, goods and services required. Uncertainty of inflation leads to fears of cost over-runs. As witness to this, 1980 estimates of the Alaska natural gas pipeline were around $15 billion and

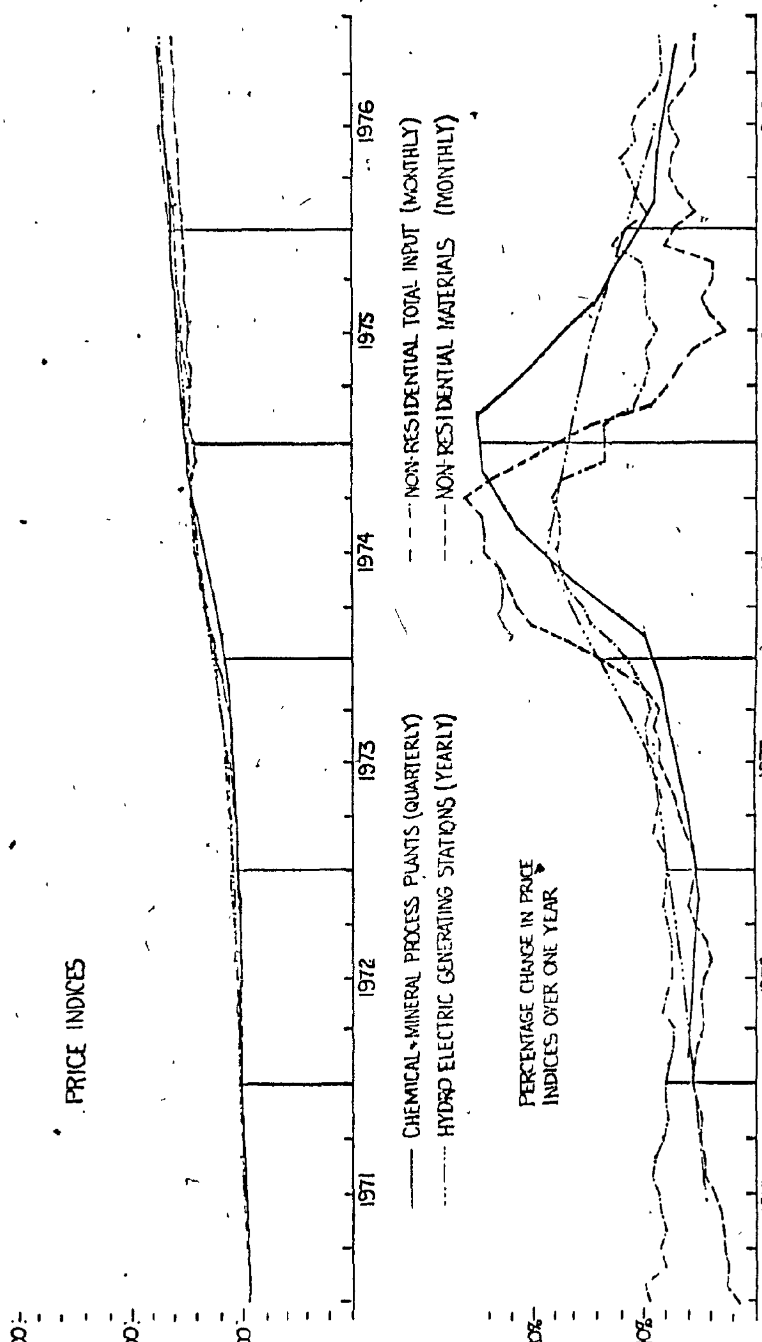


FIG. 1-1
SELECTED CANADIAN PRICE INDICES AND PERCENTAGE CHANGE FROM SAME TIME A YEAR AGO

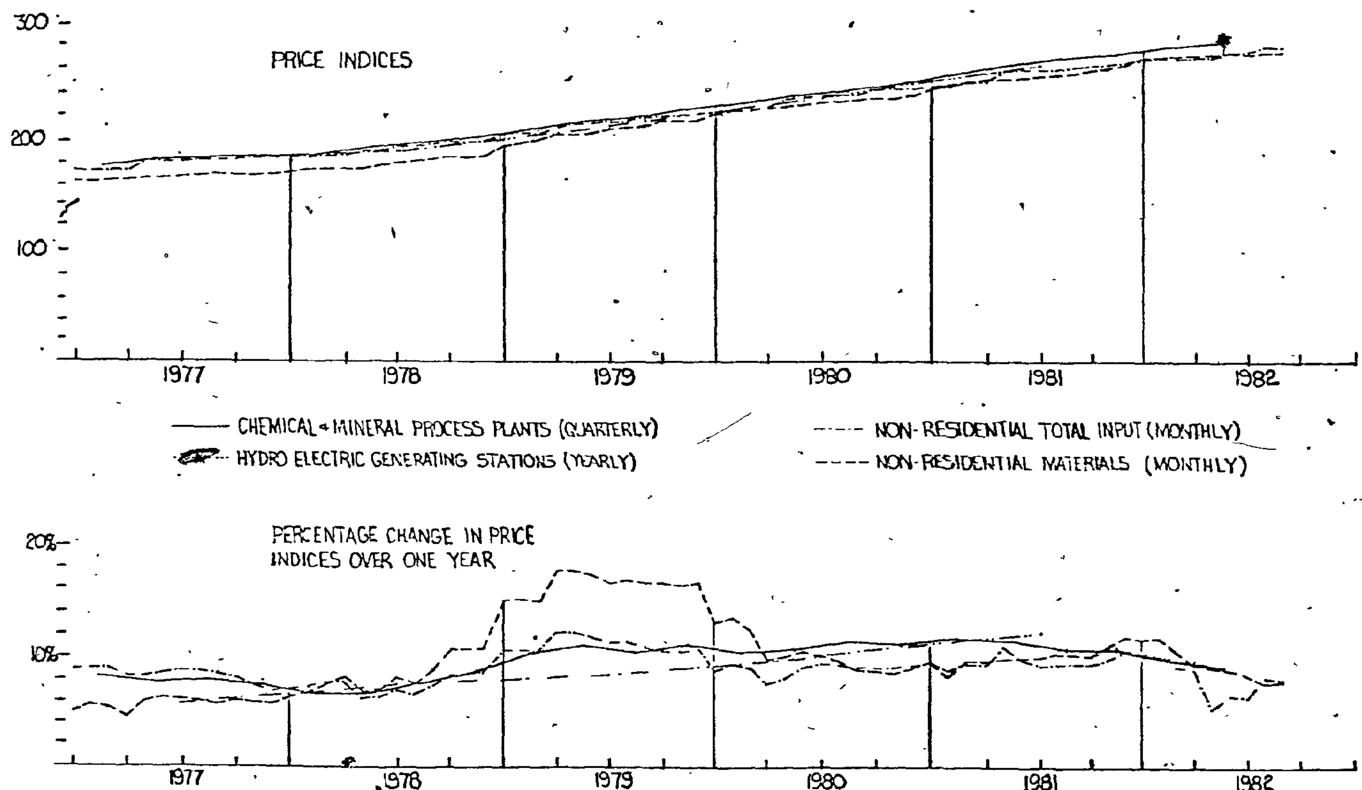

PRICE INDICES
300
200
100
1977
1978
1979
1980
1981
1982
CHEMICAL & MINERAL PROCESS PLANTS (QUARTERLY)
HYDRO ELECTRIC GENERATING STATIONS (YEARLY)
NON-RESIDENTIAL TOTAL INPUT (MONTHLY)
NON-RESIDENTIAL MATERIALS (MONTHLY)
PERCENTAGE CHANGE IN PRICE INDICES OVER ONE YEAR
20%
10%
1977
1978
1979
1980
1981
1982

FIG. 1-1 CONTD

had climbed to $40 billion or more by the time the project was put on hold in the spring of 1982.

A second source of fear is the high and unpredictable debt costs, FIG. 1-2. Any large project must be heavily financed with debt. In the long term market, where rates are fixed at the time of borrowing, lenders demand very high yields to protect their investments from future higher interest rates and inflation. Long term predictions of interest rates vary so widely that lenders charge heavily so as to minimize risk.

Short term financing rates are subject to momentary change. Over the past 4 years the charge for prime business loans at Canadian banks has swung from 8.25% to 16.75% to 12.25% to 22.75%. This volatility makes planning of debt costs virtually impossible.

A further problem facing major project development is that prices available for production are linked to world prices. The world oil price has dropped and there is belief that it won't rise as much or as steadily as once confidently predicted. This fact alone casts serious doubts on the prospects for profits from high cost mega project energy sources.

Further fear is created through current corporate leaders distrust of governments long term commitments. Large projects are highly visible to the public making them the focus of fast-changing political pressures and opinions. Even if present governments keep their promises, opposition parties

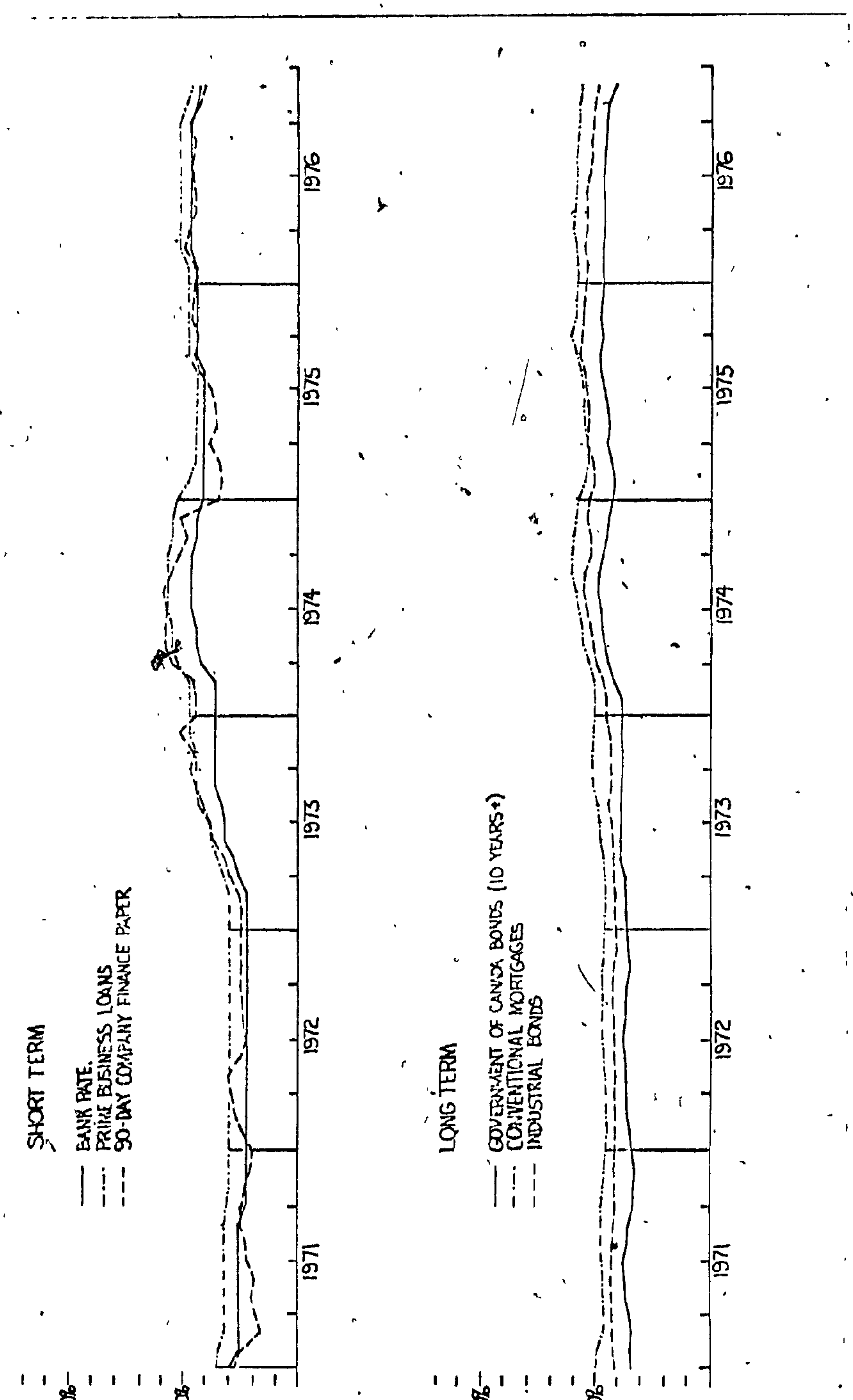


FIG. 1-2
SELECTED CANADIAN INTEREST RATES

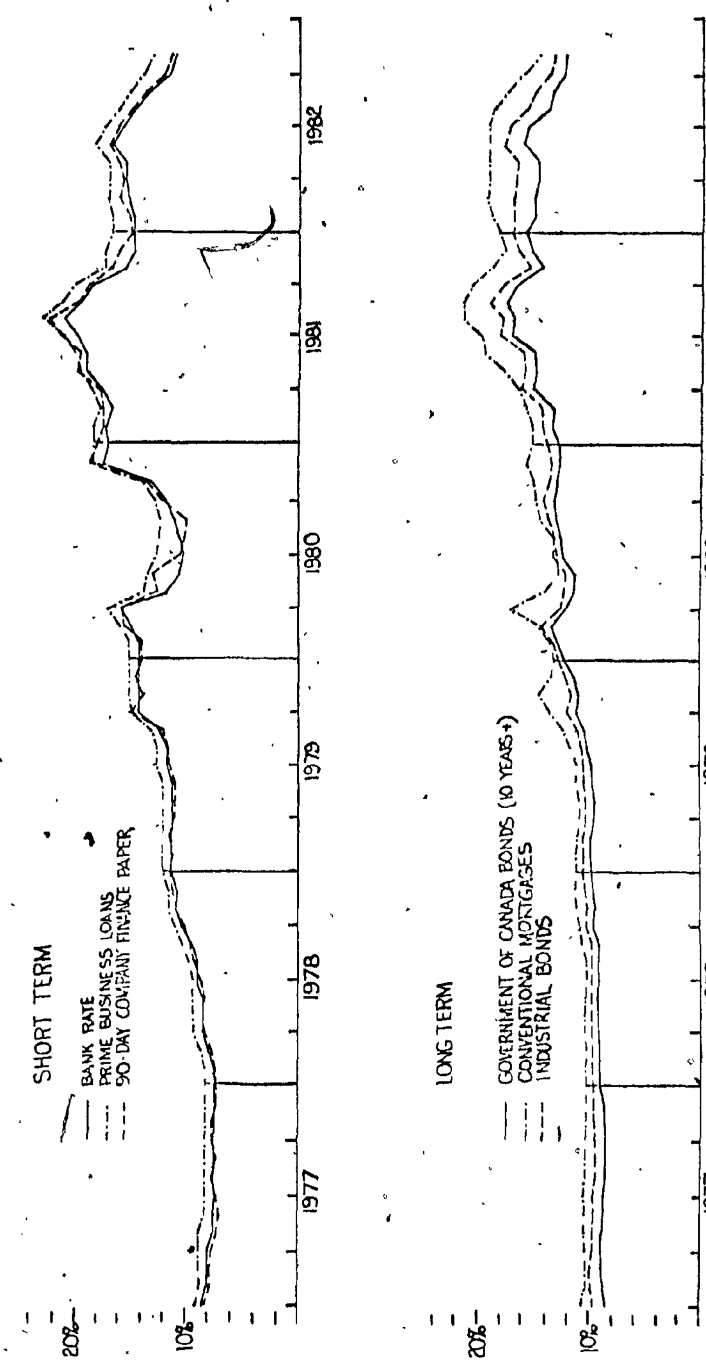

SHORT TERM
BANK RATE
PRIME BUSINESS LOANS
90-DAY COMPANY FINANCE PAPER
LONG TERM
GOVERNMENT OF CANADA BONDS (10 YEARS+)
CONVENTIONAL MORTGAGES
INDUSTRIAL BONDS
20%
10%
1977
1978
1979
1980
1981
1982

FIG.1-2 CONTD

have made it clear they may abandon them if elected. The risks for the investor are obvious as these mega projects take years to build and years more to payoff.

Starting in the early seventies an era of unpredictability or instability has been entered. This is in contrast to the relatively stable times of the nineteen fifties and sixties.

Lower corporate cash flows during the present recession in Canada, which may or may not be of short run in nature, tend to deepen corporate doubt about the future.

Other areas of concern to large project investors include the long history of federal-provincial government squabbling and resultant delays in decisions - with the investors caught in the middle. There is uncertainty about future treatment of foreign investors, about natural gas exports and about risks in technological and environmental costs of frontier production.

Present economic volatility and uncertainties about the future have led to the support, by many, of smaller scale projects which better fit the present economic conditions. However, others counter that economies of scale, allowing savings to be realized on bigger facilities, would prevent a smaller project. Some of the so called smaller projects still entail sizeable capital outlays.

Large projects remain in Canada's future interests. This would apparently imply that all the "big ones" are not necessarily dead. When confidence is again restored in government policies, inflation and interest rates decline and gain stability, and prices of resources start to rise, there is every indication that large projects in Canada will re-emerge.

The financial planning models developed in the following work will provide sound tools to aid in the determination of the financial feasibility and optimal planning strategies for these projects over their entire project life-cycle.

1-2 PROJECT LIFE-CYCLE

The life-cycle of a project begins with the decision of meeting, or the realization, of a need. Actual construction work is just the tip of the project "iceberg". Preconstruction phases can involve durations of one to three times (41) the actual construction phase. Preconstruction phases together with post-construction phases of operation and project phase-out can amount to a significant time duration. The time from realization of need to the end of project phase-out is termed the project life-cycle.

FIG. 1-3 illustrates the project life-cycle, it is not necessarily determinate. However the basic configuration of phases will remain virtually unchanged even though uncontrollable external influences may guide or shape the project life. There are many start-stop decision points throughout the life-cycle but any action that undermines the basic project rhythm can produce disastrous results. Maintaining the life-cycle logic sequence is all important in the meeting of project objectives.

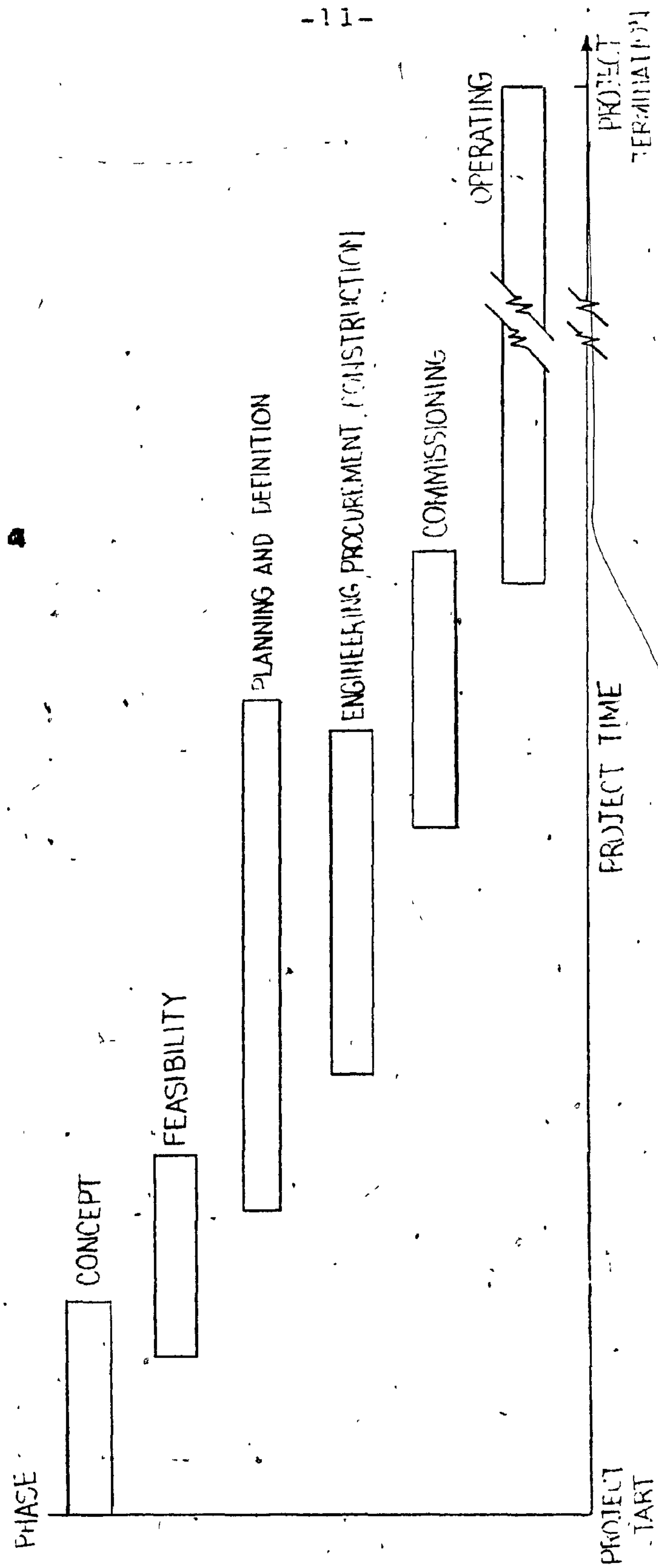


FIG. 1-3
THE PROJECT LIFE-CYCLE

A project must be considered as a dynamic entity. It may be controlled or left uncontrolled, driven along guidelines or left to follow its own course. Big or small there are never two projects exactly alike.

The concept phase begins with the realization by the owner that investment of capital into a project will produce a solution to a problem or need, or provide an opportunity. Only a few people are needed during this phase, to check facts, compile data, set objectives and to use analysis techniques in order to make comparisons and forecasts. The concept phase begins with project definition and is completed upon authorization of a budget.

Feasibility starts after the owner is reasonably assured of project viability. Results of the concept phase are reviewed and expanded upon to allow comprehensive evaluation of project alternatives. The feasibility study is used by management to assure selection of the "best" alternative. Alternatives are recommended or rejected with appropriate reasons why. The feasibility study is used to secure approval for project funding if project viability is demonstrated. Included in this phase are: marketing study, location study, sufficient preliminary engineering to provide a fairly fixed layout, and a preliminary plan and milestone schedule. Also included are preparation of preliminary or even definitive cost estimates, preliminary plans for the follow-up phases, risk and sensitivity considerations, contingency evaluation and escalation and finance cost considerations. The feasibility phase is the time during which major decisions are confirmed.

The third phase is planning and definition. In this phase, the various options and methods of implementation must be considered and evaluated. Consideration is given to the timing, financing, impacts and limitations as well as a review of many of the items considered in the feasibility analysis. The preliminary project plan establishes scope, quality, cost, time and resources in a rough or preliminary way so as to be "in the ballpark". Actual project planning establishes in detail the objectives and controls to be used in the remaining life-cycle phases. Degree of planning detail is dependent upon project size and complexity, amount of information available and the degree of control required.

Next in the life-cycle is the EPC (engineer, procure, construct) phase where the majority of project work is performed. In this phase project funds flow profusely and the effectiveness of project planning becomes evident. Facility design plans and specifications are documented in detail to produce working drawings. Materials necessary for construction are procured. Tenders are called on procurement packages, evaluated, negotiated, awarded and controlled. Finally the physical construction is undertaken in accordance with project plans, specifications and contract documents. Quality assurance and control, cost control and scheduling control are all implemented allowing interim evaluation and feedback for future use. The termination of the EPC phase provides the built facility.

Commissioning is the next phase beginning when the EPC phase is 80 to 90% complete. Planning for this phase is generally carried out during the EPC phase. This phase includes testing of all project systems, modifications and adjustments, assembly of operating manuals and system guarantees, training of actual operating staff (assuring a smooth takeover by trained operators) and obtaining final project acceptance by the owner. At the end of this phase the owner has a complete operating facility.

The final stage of the life-cycle is termed the operation phase. Here the project is producing, achieving or meeting the needs first established in the concept phase. Concern is with financial ratios, market conditions and production efficiency. The end of this phase results in project disposal when the facility is no longer economically or technologically viable.

Major decisions must be made during the early stages of the preconstruction phases. It is here that management has the greatest leeway to make changes in project scope (including temporary holds or cancellation) to meet financial constraints. During the early phases of a project the importance of decision making on overall project finance is at a maximum. However, at this stage analysis must be performed using data based on a lack of definitive project information. As the life-cycle is traversed decisions made at earlier dates impose constraints on alternatives that may be selected.

1-3 NEED FOR FINANCIAL PLANNING

"Over the last 15 years or so the financing of large projects has become an overriding factor in the evolution of all aspects of the (project) work" (3). Investment of time and effort early in the preconstruction phases of a project to create realism in financial planning is easily justifiable on large projects due to the complexity of financing and long project durations involved.

Techniques are available to the cost engineer which allow accurate estimation of project constant dollar capital costs (4). The actual timing of costs associated with construction is an important area of concern yet little in the way of generic techniques has resulted from research work conducted (7) (9) (10) (43).

Computation of project cash flow is typically obtained through the use of networking techniques (27). A project schedule is established by assigning estimated time data and activity relations. Each activity is then assigned an estimated price per unit of production (direct and indirect costs) and an estimate of the total production quantity. Cash flow magnitude and timing may then be determined by the addition of activity costs.

Two important areas of concern in network techniques are resource leveling and resource efficiency. Availability, conditions and regulations impose constraints on labour, materials, equipment and financing which can be accounted for through the use of resource leveling techniques (33). Although learning curve theory (44) has shown that resource efficiency is not uniform over the span of a project few implementations have been introduced in networking techniques to account for variation of resource efficiency.

To provide accurate creation of project cash flow profiles requires the consideration of both limited resources and efficiency variation of the resources employed over time. The first steps towards this end are presented as the Micro Model in Chapters 5 and 6.

Once the project cash flow requirements are established in terms of constant dollars, it is necessary to establish time dependent costs due to inflation and debt financing. It is important to realize that the additional capital required to finance inflation may be a significant proportion of the capital cost. Chapters 3 and 4 introduce methods that allow a project owner to establish, and to test the sensitivity of, escalation and financing costs. The models developed are termed Macro Models.

1-4 PROJECT BREAKDOWN

For analysis purposes, a project may be broken down into a project level and an activity level. Each level is characterized by specific engineering decision variables, performance measures and constraints.

At the activity level concern is with the individual activities of the overall project network. An activity is evaluated according to its duration, constant dollar cost and resource usage. An activity may be divided into sub-activities which are termed "operations" in this paper. The operation is concerned with the actual methods and processes of construction. Thus, the actual resource usages and efficiencies are defined at the operation level. The sum of the operations produce an activity and the decision variables of the operation, and thus of the activity, are the resources; men, materials, machines, methods, money and management. Uncontrollable factors affecting the activity level include local labor conditions, weather conditions and average productivity rates. Constraints imposed on the activity level are site and environmental conditions, skilled manpower availability, equipment availability, government regulations and labor regulations.

Performance measures at the project level include project duration, constant dollar cost, total dollar cost (constant dollar cost + escalation + financing) and discounting techniques (net present value and internal rate of return). Project level decision variables include the actual logic of the project network, scheduling of activities (early vs. late start schedules), amount of fast-tracking employed, extent of work packaging, procurement strategies and use of crashing (activity duration reductions). The project level is affected by uncontrollable factors such as inflation rates, debt financing rates and activity productivity rates. Site and environmental conditions, magnitude and timing of cash flows, labor availability, material and equipment availability and government regulations provide constraints at the project level.

1-5 OBJECTIVES

Tools to aid in financial planning and in selecting planning strategies at both the project and activity levels are the main objective of this work. The Macro Models are developed for analysis at the project level while the Micro Model allows examination of the issues at the activity level.

Applications and versatility of the developed models are substantiated by example. For the Macro Models an attempt has been made to identify general trends where appropriate. At the activity level it is difficult to make any overall conclusions about trends. Instead, the Micro Model's versatility is illustrated by examining a number of parameter variations.

The models developed can be used effectively by a project owner as an aid in determining project financial feasibility during the early phases of the project life-cycle when information available is limited. Sensitivity of project financial position can be investigated by allowing both controllable and uncontrollable factors to vary in the models.

Additionally, the models presented have the potential to be developed for use in both financial forecasting and financial control.

1-6 OVERVIEW

Chapter 2 introduces some of the basic requirements for the understanding of financial planning. It is provided to ensure comprehension of definitions and terms of finance used in the development of the models.

Macro Model development is presented in a generic format in Chapter 3. In Chapter 4 specific criteria are introduced to quantify the generic Macro Models. Examples are investigated and results provided to illustrate trends.

The concepts behind the activity level Micro Model are presented in detail in Chapter 5. The model is then employed in Chapter 6 to investigate versatility of the model and the sensitivity of activity level performance measures to some specific activity level decision variables.

Overall conclusions and recommendations for future work are provided in Chapter 7.

The actual computer programs used for the models of Chapters 4 and 6 are listed in Appendices A and B. Before each listing a brief description of the program is provided.

CHAPTER 2

FINANCIAL MANAGEMENT CONCEPTS

Before proceeding with the development of financial modeling, an understanding of relevant economic concepts and terminology is important. This Chapter discusses these concepts in a rather concise format that can be supplemented by referring to any economic text (34) (35). A thorough comprehension of the ideas presented here is essential to the developments presented in the rest of this work.

2-1 BASICS

An important concept in financial analysis is the time value of money. It is more desirable to secure $100 today than sometime in the future because the use of money is a valuable asset. That the availability of money is valuable is ascertained by the charging of interest.

Analysis requires comparison of the value of money at different points in time. The concept of equivalence provides the link between future and present sums of money. If there is indifference to having a sum of money now or the guarantee of receiving some quantity of money at a future date, the present sum is said to be equivalent to the future sum. This relationship allows the computation of equivalent sums at any point in time. It is important to note that equivalence is dependent on the magnitude of the interest rate.

Economic comparisons between project alternatives cannot be made in actual dollar sums that occur at different points in time unless transformed into some equivalent comparable sums of money. Through the computation of equivalent sums at the same point in time, values are obtained which may be validly compared.

Compound interest is simply the charging of interest on unpaid interest. Defining r as the annual interest rate (nominal) and m as the number of interest periods per annum then the interest rate per period is i=r/m. The present value (P) of a future sum of money (F) n years from the present is;

$$P=F/(1+r/m)**mn. \qquad \text{equation (2.1)}$$

Letting the number of interest periods per annum (m) go to infinity gives the condition of continuous compounding. The duration of the interest period decreases from a finite duration to an infinitely small duration. The continuous compounding formula is derived as follows:

$$F=P \lim_{m\to\infty} (1+r/m)**mn$$

$$=P(\lim_{m\to\infty}(1+r/m)**m/r)**rn$$

$$=P \exp(rn).$$

equation (2.2)

Nominal interest (r) is the annual interest rate without accounting for the effect of compounding during the year. Effective rate (r_e) is the annual interest rate which takes into account the effect of compounding during the year. The relationship between effective and nominal rates is given by;

$$r_e=((1+r/m)**m)-1.$$

equation (2.3)

In the limit as m approaches positive infinity the relationship becomes;

$$r_e=\exp(r)-1$$

equation (2.4)

Discounting techniques have found wide acceptance in systems of capital budgeting (5). Accounting for the time value of money in discounting techniques provides a major realistic advantage over other criteria such as payback and accounting rates of return. Internal Rate of Return and Net Present Value are the two methods of discounting employed in capital budgeting. The discounting technique relationship is;

$$NPV=\sum_{p=0}^{n}(C_p/(1+r_e)**p)$$

equation (2.5)

where NPV=Net Present Value (Worth).

C_p=Discrete end of period cash flow.

r_e=Effective Discount rate. When NPV=0 then r_e becomes the Internal Rate of Return on investment.

p=Time period of cash flow C_p.

A sound understanding of the preceeding basics is fundamental to any sort of financial analysis. Further reading on the economic basics presented can be found in any book on Engineering Economics or Financial Analysis (34) (35).

2-2 THE CASH FLOW PROFILE

Cash flow is an important issue in the analysis of any project as the amount of funds available for capital expenditures is limited. Cash flow may be defined as the movement and timing of cash with respect to a project. Movement implies either an in or out of pocket movement. Restated, cash flow is the receipt or disbursement of cash at different points in time of the project.

The cash flow of a project is established by estimating the timing and magnitude of all in and out of pocket amounts. Estimating is performed in terms of some specific point in time, normally present day costs (constant dollars).

The estimated cash flow is based on original dollars with no compensation for the variation in dollar value due to inflation or deflation.

Cash flows are traditionally assumed to occur as discrete lump sums at the end of a time period. A typical cash flow profile using this approach may look like that of FIG. 2-1. R. F. de la Mare (5) has shown that the placement of cash flows incurred are of extreme importance and should not be arbitrarily assigned to the end of a period. Sensitivity of economic analysis criteria to cash flow positioning is presented by de la Mare showing the importance of placement in foretelling project ecbnomic viability.

A method of overcoming the problems of arbritrary placement of cash flows is to allow the time period to become smaller. As the size of the time period becomes extremely small a more realistic and convenient assumption is that of continuous rather than discrete cash flows during a project. A representative continuous cash flow of a project appears in FIG. 2-2. CF(t) represents cash flow during the construction phase of a project while RF(t) is the cash flow during project operation.

The cash flow during the construction phase of a project can now be represented by considering the equation CF(t) only. In the field of cost engineering project costs are modeled by the "S" curve. The "S" curve is a plot of cumulative costs incurred during a project versus time. Costs incurred are considered continuous throughout the construction duration. The shape of the "S" curve is owing to the nature of construction projects. Cumulative construction costs are observed to normally occur at a slow rate in the beginning, moving to a faster more stable rate during the middle of construction then gradually tapering off towards termination.

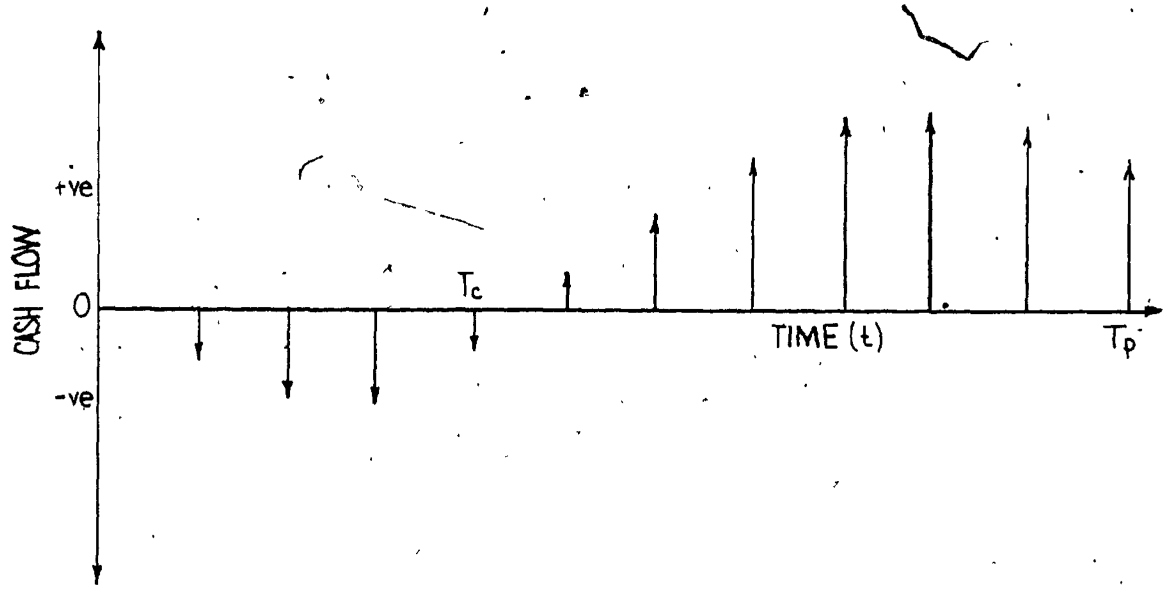


FIG. 2-1
DISCRETE END OF PERIOD
CASH FLOW

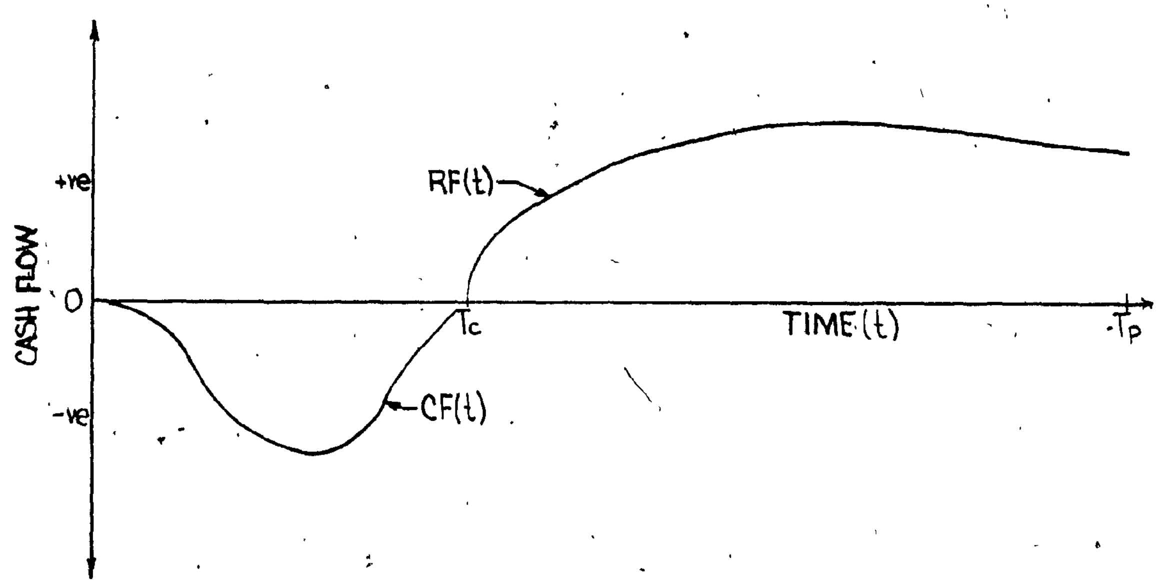


FIG. 2-2
CONTINUOUS
CASH FLOW

This "S" curve model is used extensively in project cost control and cost forecasting (12) (33) (36) (37) (38).

A typical "S" or cumulative expenditure curve for the construction phase of a project as given by a unimodal cash flow profile is shown in FIG. 2-3. For actual projects however, the "S" curve may not follow a smooth S shape. The curve for a $231 million dollar project is also shown in FIG. 2-3. Bumps in the "S" curve are caused by multiple modality of the cash flow. Dollars are the unit of the ordinate while time is the abscissa unit. The total cumulative expenditure to date, at any time during the construction, may be obtained from the curve.

The following discussion pertains to cash flows of constant dollars. The cumulative expenditure curve is typically derived from the cash flow curve. At any time t the total cumulative cost C(t) is equal to the sum of all n costs incurred during the period of time between start ($t=0$) and time t;

$$C(t)=\sum_{j=0}^{j=n} CF_j. \qquad \text{equation (2.6)}$$

The relationship between cash flow and cumulative expenditure is obtained by noting that the cash flow at any time t is the rate of change (or slope) of the cumulative expenditure curve;

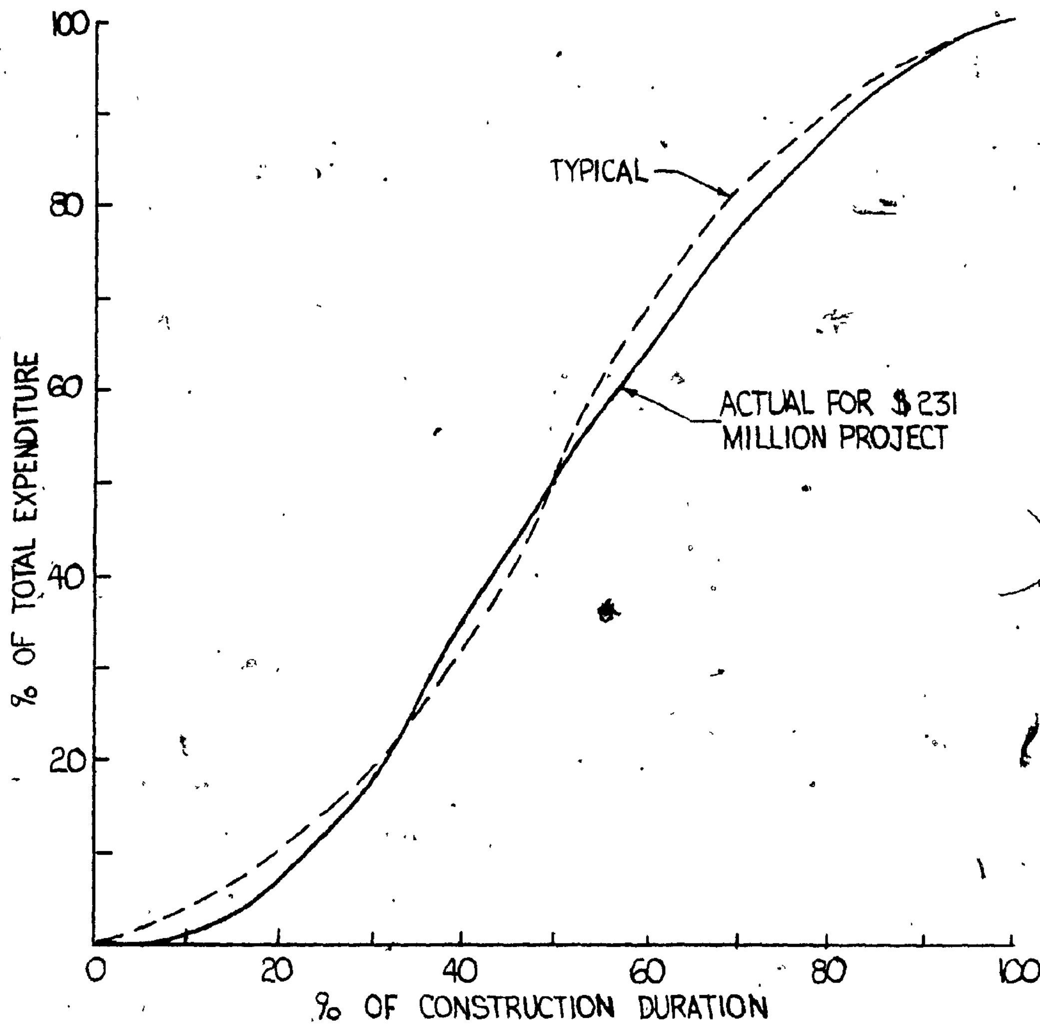


FIG. 2-3
COST S-CURVE

$$CF(t)=\lim_{\Delta t \to 0}(C(t+\Delta t)-C(t))/\Delta t = d/dt\ C(t).$$

equation (2.7)

At time Tc, the construction duration, the total capital expenditure is C(Tc) and will be referred to as the bricks and mortar cost of a project. The bricks and mortar cost is comprised of the sum of the total direct costs, Cd(Tc), and total indirect costs, Ci(Tc). Direct costs are those attributable to the resource requirements of specific construction activities. Indirect costs are attributable to general expenditures such as costs of temporary facilities and their operation rather than specific activities.

The relationship;

$$C(Tc)=Cd(Tc)+Ci(Tc)$$

equation (2.8)

is illustrated in FIG. 2-4, plotting cost versus construction duration. Total indirect costs tend to increase linearly with increasing total construction duration. Total direct costs increase if construction activity duration is shortened (crashed) or lengthened beyond optimum. For any set of defined project circumstances and/or engineering decisions a tradeoff exists between total direct and indirect costs. Theoretically an optimum construction duration, T*c, can be found which minimizes C(Tc). The creation of the direct and indirect cost curves is difficult if not impossible because of the problem of estimating resource level (engineering

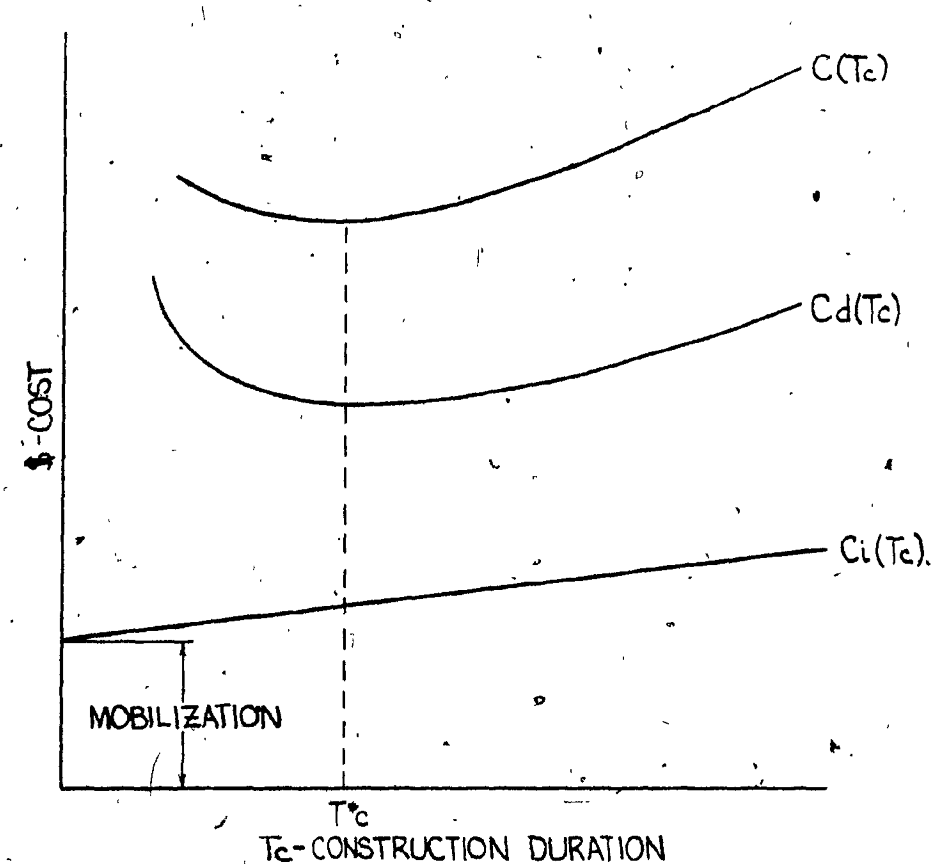


FIG. 2-4
CONSTANT DOLLAR TOTAL
COST COMPONENTS

decision variables) requirements and mixes in relation to changing durations. This in turn means location of the optimum construction duration also becomes realistically impossible to achieve.

Cumulative expenditure at any time t is;

$$C(t)=Cd(t)+Ci(t) \qquad 0 \leq t \leq Tc$$

equation (2.9)

where Tc is the construction duration. Differentiating equation (2.9) with respect to time gives;

$$d/dt\ (C(t))=d/dt\ (Cd(t))+d/dt\ (Ci(t))$$

which, using the relation of equation (2.7) can be written;

$$CF(t)=CFi(t)+CFd(t).$$

equation (2.10)

CF, CFi and CFd represent the total cash flow, indirect cost cash flow and direct cost cash flow respectively.

The rate of total capital expenditure, CF(t), (construction cash flow) is a fundamental concept of project analysis and vital to the work carried out in the following chapters.

The treatment of cash flow during project operation in significant detail is beyond the scope of this work. Reference (39) provides an introduction to the treatment of RF(t).

2-3 INFLATION

Inflation is the rise in price levels over time. It is that which makes a dollar today less valuable in the future. Inflations in Canada have not been steady and experience has been one of imperfect anticipation in inflation forecasting.

In today's environment of double digit inflation a project lasting over a significant time period will endure large cost increases due to inflation. The project cash flow of the preceding section is generally estimated in terms of constant (today's) dollars. A more vital concern is the actual (escalated) project cash flow which accounts for inflation. The existence and variability of inflation make project planning and forecasting an extremely risky task.

There are several ways that inflation may be measured and each method yields a different rate of inflation. An inflation rate is defined as the percentage change in price over some time period. Inflation may be measured as percentage change in price level from the previous month, percentage change from the previous month at annual rates, percentage change from previous quarter at annual rates or as the percentage change during some other specified time period such as one year.

After selection of method of inflation measurement a choice must be made as to what price or prices are to be measured. Government publications such as Statistics Canada provide a wide range of price indices giving relevant measures of inflation for various baskets of goods and services or economic sectors. All indices have shortcomings and none can be considered completely ideal.

Of particular interest to the construction project planner is Statistics Canada monthly bulletin entitled "Construction price statistics" (15). This publication lists input and output price indices for such sectors as non-residential building, electric utility construction, chemical and petrochemical plant construction to name a few. These indices may be helpful in determining or forecasting inflation rates for a particular project. The main drawback of these publications is the lack of readily available documentation regarding the complex formation of these indices thereby limiting their use.

A more relevant source of data for inflation measurement may be found in company records. Properly maintained and interpreted records of past work can become a valuable asset in determining and predicting expected project inflation.

Some relevant construction price indices and percentage change in indices were illustrated in FIG. 1-1. It is interesting to note the extreme volatility of the inflation rates when reported on a monthly basis. Whereas, those reported on a quarterly or yearly period (taken as the average of the monthly indices over the reported time period) tend towards functions much smoother in nature. From this diagram it appears quite plausible that inflation may be effectively modeled by linear functions.

The selection or creation of a price index or set of indices is not a trivial matter. However a choice, based on sound judgement, must be made if one is to have a suitable yardstick by which to gauge inflation.

After selection of method and choice of relevant price categories the formidable task of forecasting inflation rate movements over the life of the project still remains. Substantial research has gone into the subject of forecasting inflation rates through the use of both simple and complex econometric models. This research has provided a growing literature on inflation forecasting (16) (19) (20).

Accurate inflation forecasting is indeed desirable in project planning but extremely difficult, if not impossible to accomplish. This is particularly so under conditions of severe inflation fluctuations. Globerman and Baesel (16) have examined a few popular forecasting techniques and concluded no significant differences in accuracy.

A simple forecast model is an autogressive weighting of past inflation rates to produce future period inflation rates. The adaptive expectations autogressive model is (16);

$$\pi^*_t = \left(\sum_{\ell=1}^{n} W_\ell \pi_{t-\ell}\right) \qquad \text{equation (2.11)}$$

where π^*_t is the future period t anticipated rate of inflation, $\pi_{t-\ell}$ the actual past inflation levels, W_ℓ the past periods weight factor and n the number of past periods being considered. (Determination of appropriate weight factors is a whole problem in itself). This model uses the assumption that past results will affect or continue into the future.

Using the concept of equivalence and an expected constant level of inflation π^* a constant dollar amount can be converted to the actual expected current dollar cost at some future time n time periods away through;

$$\$current = \$constant\ (1+\pi^*)^{n} \qquad \text{equation (2.12)}$$

where π^* is the expected inflation rate per time period from time now to the end of n time periods in the future. This equation then will convert a cost given in today's (constant) dollars into the actual price at the point of occurence (current).

Considering equation (2.12) on a yearly basis and assuming θ to be the annual nominal inflation rate and m the number of inflation periods per year such that the inflation rate per time period is $\pi=\theta/m$ equation (2.12) becomes;

$$\$current = \$constant(1+\theta/m)^{mn}. \qquad \text{equation (2.13)}$$

In reality inflation is incurred on a daily basis and it may be misleading to apply it to end of time periods. For convenience and perhaps greater realism continuous compounding will be used. The number of inflation periods per year, m, is allowed to go to infinity. Equation (2.13) then yields;

$\$current=\$constant\ \exp(\theta n)$

equation (2.14)

where θ is the annual nominal inflation rate and n the number of years.

Each inflation time period cannot be expected to produce exactly the same rate of inflation. The inflation rate is time dependent, $\theta=\theta(t)$. The rate of inflation at any point in time, tp, is given by;

$$\theta=\theta(tp).$$

To convert constant dollar amounts (t=0) to current dollar amounts (t>0) requires the accounting of the variation in inflation rate with time. This is accomplished through calculation of the area under the inflation curve between t=0 and time t=tp.

A typical inflation function is shown in FIG. 2-5. The area under the θ(t) curve from t=0 to t=tp is divided into n rectangles of equal base dimension Δt. The area of a typical rectangle is;

$$\theta(t_k)\Delta t.$$

Summing the area of all such rectangles between 0 and tp and allowing the rectangle base to approach zero (the number of strips, n, goes to infinity) gives;

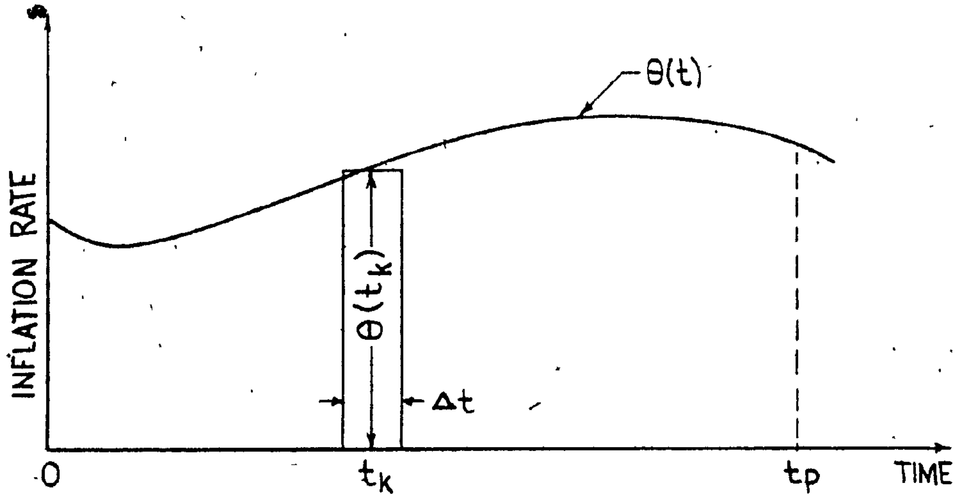


FIG. 2-5
INFLATION RATE PROFILE

$$\lim_{n \to \infty} \sum_{k=1}^{n} \theta(t_k)\Delta t = \int_{t=0}^{t=tp} \theta(t)dt. \qquad \text{equation (2.15)}$$

When $\theta(t)$ is a constant θ over n years the area under the inflation curve is simply θn. The area under a varying inflation function is given by equation (2.15). Substituting equation (2.15) in equation (2.14) for the area θn gives the conversion of constant dollars into current dollars accounting for time dependent inflation and using continuous compounding as;

$$\$current = \$constant \ \exp\left(\int_{t=0}^{t=tp} \theta(t)dt \right). \qquad \text{equation (2.16)}$$

Equation (2.16) provides the link between future and present price level difference due to inflation.

2-4 FINANCE INTEREST RATE

The use of money is a valuable asset. The charge for the use of money is interest. Thus a borrower of money is required to repay the lender the original sum (principal) plus a finance charge (interest) for having the use of the borrowed money.

Time value of money is very important in projects of significant duration. It is the escalated project costs which must be found and financed. Economy of scale, inflation and complex/innovative technology can create project costs exceeding the capabilities of even the largest of conglomorates. To meet these project costs funds must be secured from outside sources.

There are three basic types of funds available. The first is equity capital which includes stocks and retained earnings. Equity capital may more properly be considered an internal rather than an outside source. Type two is short term funds, funds borrowed for less than a year. The final type is funds secured for more than a year, long term funds. Today short term money markets are very active causing declining long term fund availability. This trend has forced up interest rates in capital markets. The problem to the borrower is that short term interest rates can be extremely volatile in reaction to changes in money supply and demand.

Source options available to a project are dependent on whether a project is domestic or international in nature. Sources of funding include commercial banks which provide most short term funding, in the form of loans and lines of credit, or long term loans and commercial mortgages in collaboration with institutional investors. Venture capital firms can be created to provide financing for small corporations. The security market is another source and consists of investment bankers, primary capital markets and secondary security markets. Another source is national governments through such vehicles as the Export Development Corporation in Canada which operates on behalf of foreign projects.

The amount of money to be internally generated and externally secured requires careful financial consideration. Ideally funds will be borrowed only in the amounts and at the times for which they are needed so that no borrowed funds remain idle and that no fund shortages occur. In practice this is impossible to achieve and safety margins must be incorporated.

The choice of fund source and type are generally dependent on the industry type of the proposed project. Large project investments have led to innovative financing techniques. A major development has been the use of joint venture ownerships allowing for the pooling of resources and the spreading of possible financial failure among a number of partners.

Uniqueness of large projects today dictates that financial packages be tailored to suit each specific project. However the major innovation common to these packages has been the use of complex borrowing arrangements tied directly to the individual project. This innovation has been termed Project Financing and defined as "a financing of a major economic opportunity which the sponsor has segregated from the assets and general purpose obligations of the company. The project borrowings are typically secured by the assets and repaid by the cash flow of the project itself, but may be supported by undertakings from the sponsoring company and other third parties" (30). The interest rate charged through project financing is generally a floating rate tied to macro economic indicators such as the Prime Rate.

In financial planning suitable interest rates must be selected and forecast over the life of the project. During preliminary analysis final fund sources may not yet be known and suitable interest rates based on experience and judgment must be selected. Debt interest rate for project finance is usually one to two percentage points above parent company borrowing rate (30).

Short and long term Canadian interest rates were illustrated in FIG. 1-2. Both short and long term rates, since late 1979, have been extremely volatile. Interest rates before 1980, particularly long term rates, remained fairly constant and thus more predictable in nature. As can be seen, modeling interest rates by a linear function representation would prove adequate for all but the last three years.

As in inflation rate forecasting much research has gone into forecasting of interest rates. The movement of interest rates is in general a macro economic phenomenon but smaller economic considerations also affect the rate charged to the borrower. Studies carried out by Fraser (17) conclude that complex econometric models provide no more accuracy than the simple assumption that next years rates will be the same as this year. This is not to say that modeling cannot be useful but that careful consideration should be given to the amount of time and effort invested in producing a forecast. At the macro economic level of analysis the Fisher Relationship is generally accepted as a base model (40). The relation states that interest rates charged are composed of a relatively stable real rate plus a premium for expected inflation. The expected inflation rate is of course tied to whether consideration is being given to a short, medium, or long term. It can be seen that the forecasting of interest rate is dependent on inflation forecasting.

With the creation of the estimated project cost the required amount of borrowed funds can be estimated. The amount and timing of funds from outside sources is determined by subtracting the profile of internal sources of funds from the escalated cash flow profile FIG. 2-6.

If an amount of money is borrowed for a period of time the amount that must be repaid at the end of the period is;

$$\$owed=\$borrowed\ (1+i^*)**n \qquad \text{equation (2.17)}$$

where i^* is the constant expected rate of interest from the time the amount is borrowed to the end of n time periods. This simple compound interest equation converts amounts borrowed into amounts owed assuming a fixed rate of interest.

Assuming a yearly time basis, with r being the annual nominal interest rate and m the number of interest time periods per year, interest per unit time period is $i=r/m$ and equation (2.17) becomes;

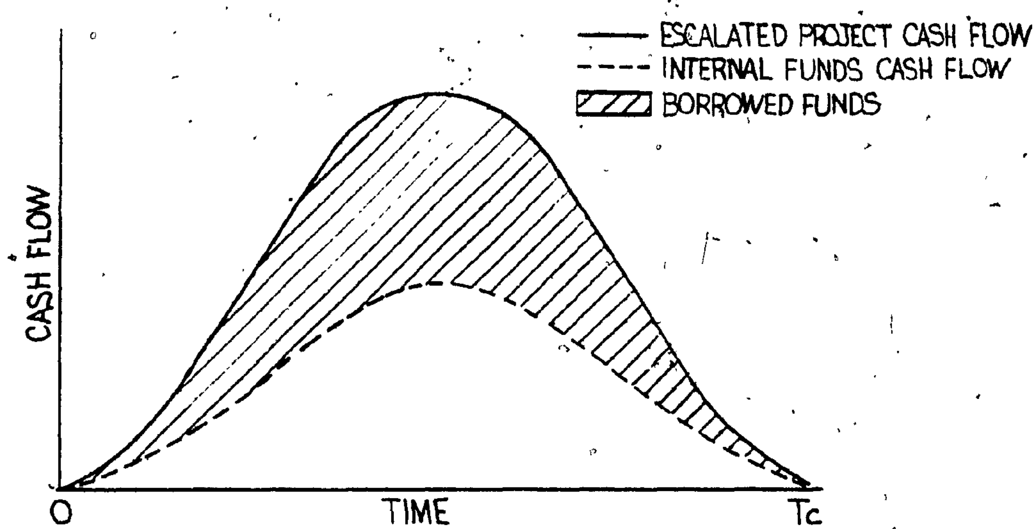


FIG. 2-6
FUNDING REQUIREMENTS

$owed=$borrowed (1+r/m)••mn.

equation (2.18)

Borrowed funds generally flow continuously into a project so that it is more realistic and convenient because of changing rates to use continuous compounding. Letting m, the number of interest periods, go to infinity the relation becomes;

$owed=$borrowed exp(rn)

equation (2.19)

where r is the annual (nominal) interest rate and n the number of years the amount is borrowed for.

As is well evidenced today the interest rate does not remain constant but fluctuates with the passing of time. The rate of interest at any point in time may be given by r=r(t) as shown in FIG. 2-7. An amount is borrowed at time 0 and is to be repaid at time tp. To account for the time dependency of interest rate the area under the r(t) curve is divided into n rectangles all having equal base width Δt. The area of a typical rectangle is;

$$r(t_k)\,\Delta t.$$

equation (2.20)

Summing the area of all n rectangles between 0 and tp and allowing Δt to approach zero;

$$\lim_{n\to\infty}\sum_{k=1}^{n} r(t_k)\Delta t=\int_{t=0}^{t=tp} r(t)\,dt.$$

equation (2.21)

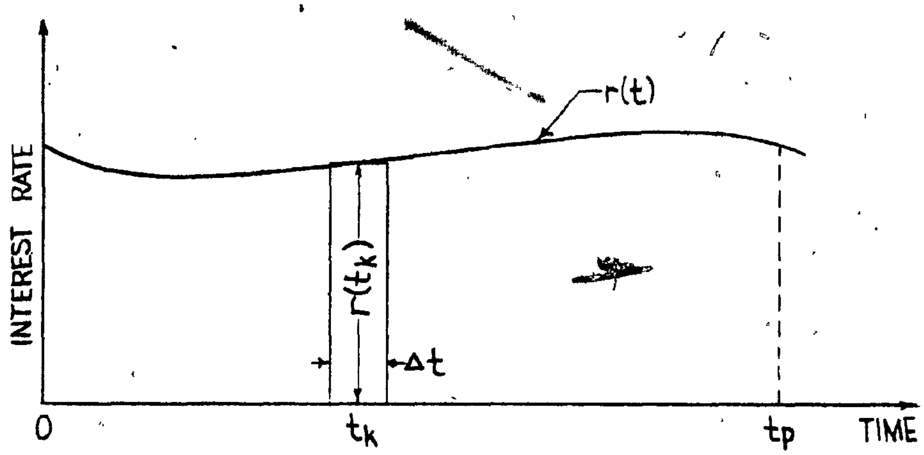


FIG. 2-7
INTEREST RATE PROFILE

Thus conversion of borrowed amounts into amounts owed under fluctuating interest rate and continuous discounting is achieved by;

$$\$owed=\$borrowed\ \exp\left(\int_{t=0}^{t=tp} r(t)dt\right)$$

equation (2.22)

where the time period 0 to tp is the time which the amount is borrowed for.

2-5 INTEREST AND INFLATION RELATIONSHIP

That interest rates are affected by inflation finds near universal acceptance in economics. The problem remaining however is in finding a means of quantifying this relationship. Complex models have been developed all using as their base the Fisher Relation introduced in the previous section. The Fisher Relation states that interest rate responds to inflationary expectations;

$$r=R+\pi^{*}.$$

equation (2.23)

In equation (2.23) r is the nominal annual interest rate, R the expected real return rate and π^{*} the expected inflation rate. The real return rate is essentially the interest at which the lender is willing to lend money so as to be covering expenses and profit.

At the root of interest rate determination is the problem of forecasting inflationary expectations. The selection of suitable inflation measuring methods remains a difficult task (19). Actually interest rate is dependent on more economic variables than those represented in the Fisher equation. More complex models build upon the Fisher model and have included up to half a dozen variables (18) (20) which, by reference to historic data, have been shown to not yet capture the true composition of interest rates.

In addition to the factors affecting interest rate at the macro economic level the planner must be concerned with project specifics. Project type, project location, financial requirements and other risks are but a few of the concerns to the lender and hence influence the interest rate charged. The riskier the project the higher the interest charged. The Fisher equation may be extended to include a project risk term, PR;

$$r = R + \pi^{*} + PR. \qquad \text{equation (2.24)}$$

Quantitative modeling of interest-inflation relationship is a very complex problem and subject to ongoing research. Of importance is that a relationship does indeed exist. Secondly, interest rate is generally conceded to be affected by inflationary expectations rather than actual inflation rates (18) (19) making interest rate prediction very difficult.

2-6 SUMMARY

The concepts and terms introduced in this chapter will be put to use in the financial models developed in subsequent chapters. A sound understanding of this chapter is essential in order to make meaningful use of project economic analysis techniques.

Many ideas of ongoing research and debate have been touched on only briefly in the sections on cash flow, inflation and debt interest.

Financial planning requires that values be assigned to variables over an unknown future. It must be remembered that financial modeling can be used effectively only through exhibiting good judgment and understanding.

CHAPTER 3

PROJECT LEVEL FINANCIAL ANALYSIS

In this chapter the Macro Models of the project level are developed. These models provide a means of quantifying the impacts of escalation and financing charges of the project. Therefore, it follows that through the use of these models the potential benefits of accelerating project construction can be measured and compared. This analysis is aided by the concept of the project breakeven curve.

Project construction duration, cash flow profile, constant dollar cost, current dollar cost and net present value are the project level performance measures incorporated in the Macro Models. The models allow observation of how project financial decisions impact upon project level decision variables and vice versa.

3-1 CONSTRUCTION DURATION

The time duration from project start to the end of construction is a factor of utmost concern. The less time required for this duration the sooner the facility can come on line and start to provide a return to the investor. The time period from the project start to the end of the construction phase will be referred to as the construction duration. There are of course constraints imposed when attempts are made to reduce the construction duration. Site and environmental conditions, cash flow levels, economic conditions, manpower availability and material availability are but a few of the myriad of factors limiting the degree of duration minimization possible.

In the models, construction duration is treated exogenously. Nevertheless the models can be used effectively in an analysis of project construction duration. Selection of duration exogenously is consistent with methods employed in well known network scheduling techniques. Activities comprising the project level network must be assigned proper time durations if a meaningful construction duration is to be obtained. An estimate of activity duration is based upon proposed project methods and resources. Durations will typically be established from historical data. With activities assigned durations and precedence relationships, standard CPM (Critical Path Methods) techniques can be employed to obtain total construction duration (32) (33).

For convenience and consistency time will be assigned units of years for project level analysis. This restriction can be readily relaxed upon thorough comprehension of the models.

With estimated construction duration established, additional financial performance measures at the project level can be determined. Further, the project construction duration can be varied if values computed for other performance measures prove to be unacceptable.

3-2 CONSTANT AND CURRENT DOLLAR CONSTRUCTION COST

One of the most frequently prepared cost estimating display techniques over the construction duration is the S-curve. The S-curve is a plot of cost versus time. Cash flow can be described in (1) current dollar terms (i.e., the actual dollar cash flows expected) and (2) constant dollar terms (i.e., equivalents of the actual dollar cash flows).

Escalation cost determination is a desired goal of the Macro Models. For this reason (and perhaps others) it is advantageous to produce the project cash flow estimates in terms of constant dollars. This then simplifies the calculation of the escalated cash flow and determination of escalation costs under any inflation profile scenario. Throughout the rest of this work it is assumed that all cash flow estimates are prepared in terms of constant dollars.

The relationship between constant dollar cumulative expenditure, C(t), and constant dollar cash flow, CF(t), is provided in equation (2.7) Rearranging this equation allows expressing the cumulative expenditure at any time tp as;

$$C(tp) = \int_{0}^{tp} CF(t)\,dt \qquad \text{equation (3.1)}$$

where CF(t) is presented in terms of time t=0 dollars and time t=0 is the project start. Thus the total area under the constant dollar cash flow profile equals the total constant dollar project capital expenditure, C(Tc), exclusive of escalation and financing charges.

Escalated (current) costs and cash flow, rather than constant dollar costs and cash flow, are of immense importance in financial analysis. It is the escalated cash flow which must be met and financed. The relationship between current dollar and constant dollar flows using a time dependent inflation rate and continuous discounting is given in equation (2.16).

There are numerous cost categories that comprise the overall project cost. Cost categories, such as materials, equipment, labor etc. each possess a unique inflation rate profile over the duration of the project. Cost categories are summed together to produce one overall cost and it will be initially assumed that inflation rates for individual categories can be combined to produce one overall inflation rate profile. (This restriction is introduced to simplify development but can be relaxed). Thus, only one overall price index for the project type need be determined.

Establishing an overall project inflation is no trivial matter but it does, however, follow upon Statistics Canada categorization of price indices by overall construction type (i.e., power plants, commercial office buildings, petro-chemical plants etc.). The problem remains with the complexity of creating these indices and a lack of corresponding documentation. The so called overall project inflation rate will be represented by $\theta(\tau)$ (see FIG. 3-1) where τ is time. To be consistent, time $\tau=0$ will be defined as being the project start. As time $\tau=0$ is today, the inflation function for $\tau>0$ must be forecast.

The escalated project capital cost is determined by using the constant dollar cash flow and the inflation rate profile. The area under the constant dollar cash flow function, CF(t) of FIG. 3-2, is divided into n rectangles of equal width Δt. For an increment of time Δt the capital expenditure in terms of constant dollars over the increment is given by the area of the rectangle;

$$\Delta C(t_k)=CF(t_k)\Delta t. \qquad \text{equation (3.2)}$$

The discrete constant dollar amount, $\Delta C(t_k)$, is converted to a current dollar cost by the relation of equation (2.16). Current dollar amount, $\Delta Cc(t_k)$, is;

$$\Delta Cc(t_k)=\Delta C(t_k)\ \exp\left(\int_{\tau=0}^{\tau=t_k}\theta(\tau)d\tau\right) \qquad \text{equation (3.3)}$$

and substituting equation (3.2) into equation (3.3) gives;

$$\Delta Cc(t_k)=CF(t_k)\ \exp\left(\int_{\tau=0}^{\tau=t_k}\theta(\tau)d\tau\right)\Delta t. \qquad \text{equation (3.4)}$$

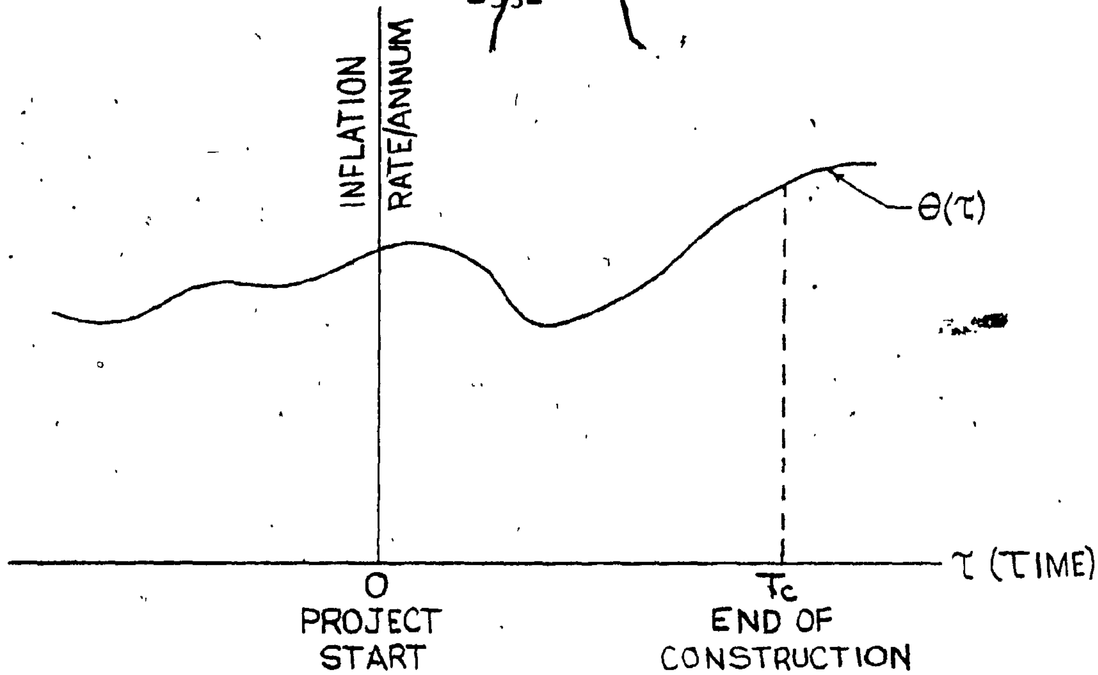


FIG. 3-1
PROJECT INFLATION RATE PROFILE

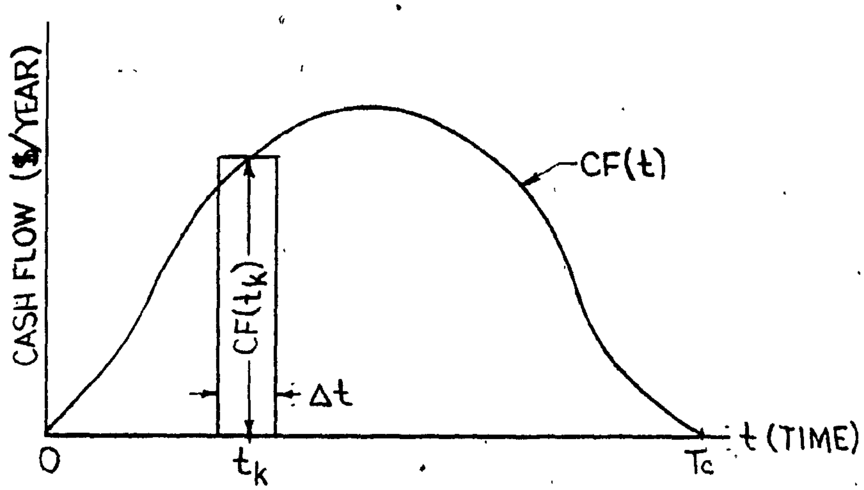


FIG. 3-2
CONSTANT DOLLAR CASH FLOW PROFILE

Summing for all n rectangles under the constant dollar cash flow profile gives the cumulative project capital expenditure in terms of current dollars, Cc(Tc). Allowing the rectangle base width Δt to approach 0 gives;

$$Cc(Tc)=\lim_{n\to\infty}\sum_{k=1}^{n} CF(t_k)\ \exp\left(\int_{\tau=0}^{\tau=t_k}\theta(\tau)d\tau\right)\Delta t$$

$$=\int_{t=0}^{t=Tc} CF(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau\right)dt. \qquad \text{equation (3.5)}$$

It follows that current dollar cumulative expenditure at any time tp is;

$$Cc(tp)=\int_{t=0}^{t=tp} CF(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau\right)dt \qquad \text{equation (3.6)}$$

where $0\leq tp\leq Tc$.

Escalated project cash flow profile, CFc(t), is obtained through application of equation (2.7) to equation (3.6);

$$CFc(t)=CF(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau\right). \qquad \text{equation (3.7)}$$

The assumption of one overall project inflation rate can be readily relaxed to include as many cost categories as deemed necessary. If there are n cost categories each having a constant dollar cash profile, $CF_i(t)$, and an inflation rate profile, $\theta_i(\tau)$, the current dollar cumulative cost at any time tp is;

$$Cc(tp)=\sum_{i=1}^{n}\int_{t=0}^{t=tp} CF_i(t)\ \exp\left(\int_{\tau=0}^{\tau=t} \theta_i(\tau)d\tau\right)dt.$$

equation (3.8)

Equation (3.5) gives current dollar project capital cost for a project having a construction duration from time t=0 to t=Tc. Capital expenditure can also be found for a project slated to begin at any time in the future. Thus, if during the conceptualization stage a project is put on hold until some future date, and assuming the cash flow profile maintains a constant shape, the capital expenditure in actual dollars can be determined. If the project is slated to begin at time $t=0_f$, where $0_f>t=0$, and has a duration lasting from time $t=0_f$ to $t=Tc_f$ the project current dollar cost estimate is;

$$Cc(Tc_f)=\int_{t=0_f}^{t=Tc_f} CF(t)\ \exp\left(\int_{\tau=0}^{\tau=t} \theta(\tau)d\tau\right)dt$$

equation (3.9)

where $\theta(\tau)$ must be forecast over time t=0 to time $t=Tc_f$.

3-3 CONSTRUCTION DEBT: PRINCIPAL AND INTEREST

Funds from outside sources may be borrowed at different interest rates but it will be assumed for project level analysis that one overall interest rate can be formulated for the entire project. The overall project debt interest rate is represented by $r(\tau)$, FIG. 3-3, where τ is time. The project start is again defined as being $\tau=0$ to maintain consistency. Interest rates for $\tau>0$ must of course be forecasted.

If an amount, \$BPS, is borrowed at the project start ($\tau=0$), the amount owed, \$OEC, at the end of construction, Tc, is given by equation (2.22):

$$\$OEC=\$BPS\ \exp\left(\int_{\tau=0}^{\tau=Tc} r(\tau)d\tau\right).$$

equation (3.10)

Similarly if at time t^*, where $0\leq t^*\leq Tc$, a current dollar amount, $\$BPt^*$, (dollars in terms of time t^*) is borrowed, the amount owed at the end of construction will be;

$$\$OEC=\$BPt^*\exp\left(\int_{\tau=t^*}^{\tau=Tc} r(\tau)d\tau\right).$$

equation (3.11)

In calculating the amount owed on borrowed funds for a project the following assumptions have been made. First, borrowed funds flow continuously into the project. This assumption follows from the continuous outflow of money to meet project costs. Second, draws are to be made in direct proportion to equity input. This is a realistic requirement in project financing (29). Lastly, repayment of principal and interest on borrowed amounts does not fall due until construction termination. This type of arrangement is termed bridge financing. These assumptions are selected so as to maintain the significant considerations of project financing. The models can be expanded to include other considerations such as advance payments and standby fees but the additional complexity required was deemed unwarranted at this stage. Castle (29) provides more detailed information on some of the considerations of project financing.

It is of extreme importance to realize that it is current dollar costs which must be financed. The higher the inflation rate the greater the project current dollar cost. These higher costs must in turn be financed at resulting higher debt interest rates due to upward pressure on the interest rate caused by higher inflation.

In the following derivation f represents the constant equity fraction input of the total current dollar capital expenditure. The equity input fraction is assumed independent of the rate of debt interest. (The validity of this assumption has not been confirmed).

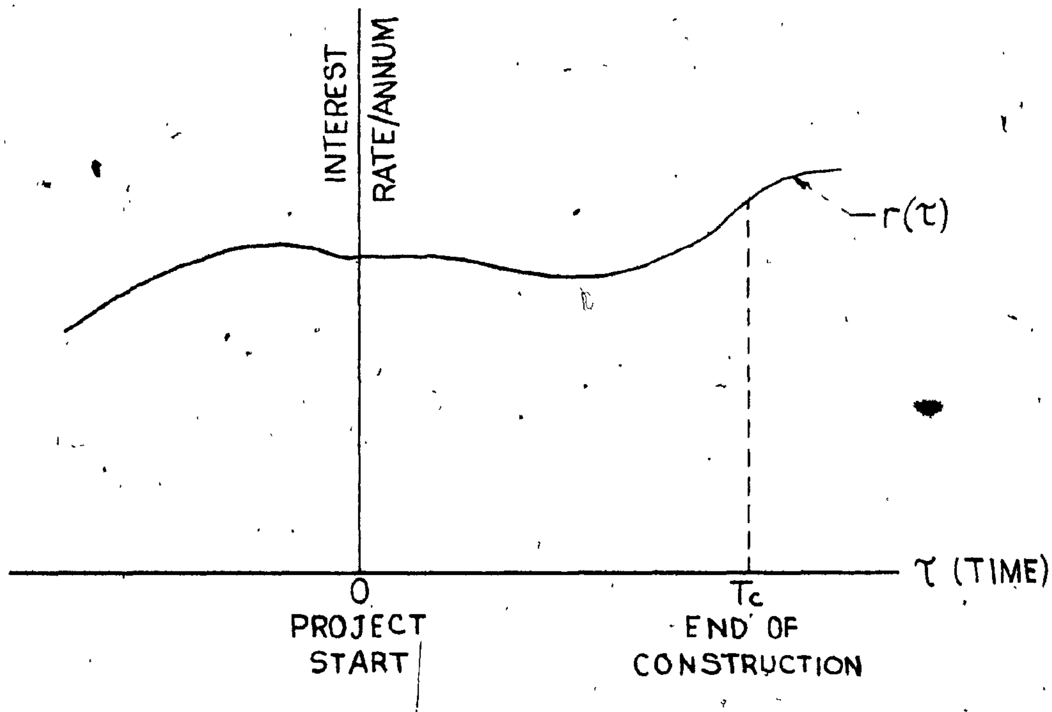


FIG. 3-3
PROJECT INTEREST
RATE PROFILE

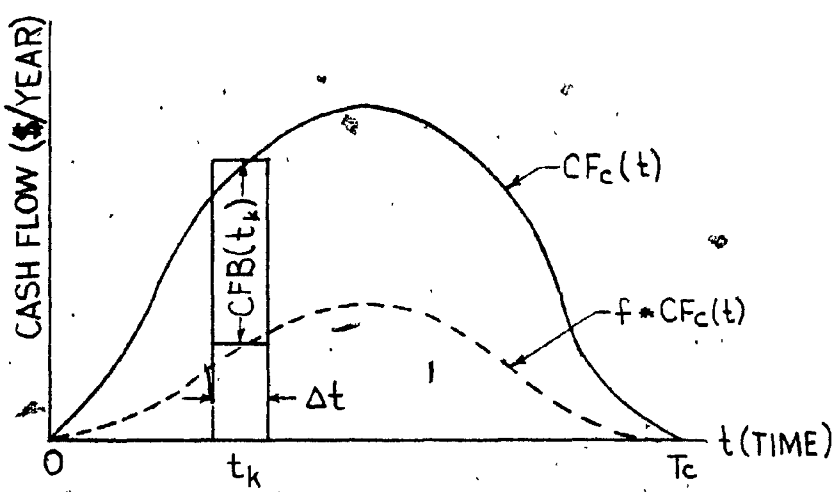


FIG. 3-4
CURRENT DOLLAR CASH
FLOW PROFILE

The project total debt is determined by considering the escalated project cash flow profile, CFc(t), and the equity input cash flow profile, f•CFc(t). Referring to FIG. 3-4 the cash flow of borrowed funds, CFB(t), is given by;

$$CFB(t)=CFc(t)-f\cdot CFc(t)=(1-f)\ CFc(t). \qquad \text{equation (3.12)}$$

The area under the current dollar cash flow profile is divided into n rectangles of equal width Δt. For a typical time increment Δt the amount of borrowed funds, ABF, is given by the area of the rectangle between the escalated and equity cash flows;

$$ABF(\Delta t)=CFB(t_k)\Delta t. \qquad \text{equation (3.13)}$$

The amount owed at the end of the construction duration for the amount borrowed over the time period Δt, ABF(Δt), is given by equation (3.11);

$$\$OEC=ABF(\Delta t)\ \exp\left(\int_{\tau=t_k}^{\tau=Tc} r(\tau)d\tau\right). \qquad \text{equation (3.14)}$$

Substituting equation (3.13) into equation (3.14) gives;

$$\$OEC=CFB(t_k)\ \exp\left(\int_{\tau=t_k}^{\tau=Tc} r(\tau)d\tau\right)\Delta t. \qquad \text{equation (3.15)}$$

Summing over all n rectangles under the current dollar cost cash flow profile gives the total amount owed, principal plus interest, at construction completion. Letting the rectangle width, Δt, approach zero gives the total amount owed at the end of construction, T$OEC, as;

$$T\$OEC = \lim_{n\to\infty} \sum_{k=1}^{n} CFB(t_k)\ \exp\left(\int_{\tau=t_k}^{\tau=Tc} r(\tau)d\tau\right)\Delta t$$

$$= \int_{t=0}^{t=Tc} CFB(t)\ \exp\left(\int_{\tau=t}^{\tau=Tc} r(\tau)d\tau\right)dt.$$

equation (3.16)

By substituting equation (3.7) into equation (3.12) and then putting the resulting equation into equation (3.16) the amount owed is;

$$T\$OEC = (1-f)\int_{t=0}^{t=Tc} CF(t)\ \exp\left(\int_{\tau=0}^{\tau=t} \theta(\tau)d\tau + \int_{\tau=t}^{\tau=Tc} r(\tau)d\tau\right)dt.$$

equation (3.17)

This equation for the total amount owed at the end of construction due to all borrowing during the construction phase is comprised of both principal and interest charges.

3-4 CONSTRUCTION TOTAL COST

Total project construction cost, TC(Tc), is a project level performance measure that is easily comprehended. Total cost is a function of the construction duration, Tc. Summation of the constant dollar total cumulative expenditure, C(Tc), costs due to escalation, E(Tc), and the costs of financing, F(Tc), gives project total cost. The relationship is;

$$TC(Tc)=C(Tc)+E(Tc)+F(Tc). \qquad \text{equation (3.18)}$$

In project performance analysis the goal is to minimize project construction costs while still obtaining the desired facility;

$$\text{minimize}(TC(Tc)). \qquad \text{equation (3.19)}$$

Project total constant dollar capital expenditure, C(Tc), is given by equation (3.1), setting tp=Tc.

Project escalation cost, E(Tc), is the difference between the project current and constant dollar capital expenditure required to construct the facility. Total project capital expenditure in terms of current dollars, Cc(Tc), is given by equation (3.5). Escalation cost is then;

$$E(Tc)=Cc(Tc)-C(Tc)$$ equation (3.20)

and upon substitution of right hand side terms becomes;

$$E(Tc)=\int_{t=0}^{t=Tc} CF(t)\ \exp\left(\int_{\tau=0}^{\tau=t} \theta(\tau)d\tau\right)dt-\int_{t=0}^{t=Tc} CF(t)dt$$

equation (3.21)

where t=0 is the project start and time at which costs represented in CF(t) were calculated.

The project finance cost, F(Tc), is equal to the total amount owed at construction completion less the amount of dollars borrowed. F(Tc) is the charge levied for the use of the borrowed funds. Principal plus interest owed at the end of construction is given by equation (3.17) and the total amount borrowed by equation (3.12), thus;

$$F(Tc)=(1-f)\int_{t=0}^{t=Tc} CF(t)\ \exp\left(\int_{\tau=0}^{\tau=t} \theta(\tau)d\tau+\int_{\tau=t}^{\tau=Tc} r(\tau)d\tau\right)dt$$
$$-(1-f)\int_{t=0}^{t=Tc} CF(t)\ \exp\left(\int_{\tau=0}^{\tau=t} \theta(\tau)d\tau\right)dt.$$

equation (3.22)

All the terms of equation (3.18) for project total cost have been defined. Substituting terms into the right hand side of equation (3.18) and cancelling like terms gives project total cost as;

$$TC(Tc)=(1-f)\int_{t=0}^{t=Tc} CF(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau+\int_{\tau=t}^{\tau=Tc} r(\tau)d\tau\right)dt$$
$$+f\int_{t=0}^{t=Tc} CF(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau\right)dt.$$

equation (3.23)

Total project cost is a very useful project level performance measure. It is a measure that can be easily conveyed and compared in the field or in the boardroom. The components comprising total project cost lead to the concept of the project breakeven curve.

3-5 THE BREAKEVEN CURVE: TOTAL COST

For a given project the construction duration is estimated to be Tc* and the constant dollar capital estimate as C(Tc*). As shown in the previous section Tc* and C(Tc*) are used in obtaining the total project construction cost TC(Tc*). The terms in the project total cost relation are all functions of construction duration. Thus changing construction duration will affect C(Tc), E(Tc) and F(Tc). Shortening the construction duration will lower escalation and finance costs but will normally increase constant dollar capital cost as additional resources must be employed to meet the shortened schedule. Therefore a tradeoff exists between C(Tc) and the terms E(Tc) and F(Tc).

The breakeven curve indicates by how much C(Tc) can change (where Tc is any construction duration) under the restriction that the total project cost remains a constant amount TC(Tc*). An assumption used in breakeven curve development is that the constant dollar cash flow profile for any duration Tc maintains the same profile shape as that used in determining C(Tc*).

The project constant dollar cash flow profile can be represented by;

$$CF(t)=C(Tc^*)\cdot cf(t)$$

equation (3.24)

where cf(t) is the cash flow profile function assuming a unit constant dollar total capital expenditure, c(t). The profile cf(t) is referred to as the normalized profile having c(Tc)=1. Thus the project's cash flow time axis, established for Tc*, is normalized so as to allow it to be stretched or compressed to meet any project duration.

Using equation (3.24) and equation (3.23), the total project construction cost for a construction duration Tc* is;

$$TC(Tc^*)=(1-f)\int_{t=0}^{t=Tc^*} C(Tc^*)\cdot cf(t)\cdot \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau+\int_{\tau=t}^{\tau=Tc^*}r(\tau)d\tau\right)dt$$
$$+f\int_{t=0}^{t=Tc^*} C(Tc^*)\cdot cf(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau\right)dt$$
$$=C(Tc^*)\ BE(Tc^*)$$

equation (3.25)

where BE(Tc*) is given by dividing TC(Tc*) by C(Tc*). For any other construction duration, $TC \neq Tc^*$, the total project construction cost is;

$$TC(Tc)=(1-f)\int_{t=0}^{t=Tc} C(Tc)\cdot cf(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau+\int_{\tau=t}^{\tau=Tc} r(\tau)d\tau\right)dt$$
$$+f\int_{t=0}^{t=Tc} C(Tc)\cdot cf(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau\right)dt$$
$$=C(Tc)\ BE(Tc)$$

equation (3.26)

where C(Tc) represents the capital expenditure that is incurred when the construction duration is changed from Tc* to Tc.

The breakeven curve establishes for any construction duration, Tc, what value of C(Tc) can be incurred without any change in total project cost from TC(Tc*). The breakeven requirement is;

$$TC(Tc)=TC(Tc^*).$$

equation (3.27)

Substituting for TC(Tc) and rearranging terms gives the equation of the breakeven curve;

$$C_{BE}(Tc)=TC(Tc^*)/BE(Tc)$$

$$=TC(Tc^*)/((1-f)\int_{t=0}^{t=Tc} cf(t)\cdot\exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau+\int_{\tau=t}^{\tau=Tc}r(\tau)d\tau\right)dt$$

$$+f\int_{t=0}^{t=Tc} cf(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau\right)dt).$$

equation (3.28)

The essence behind the breakeven curve is that shortening the construction duration means less exposure to inflation and interest which results in lower escalation and interest costs. This in turn means that capital expenditure, C(Tc), can be allowed to increase up to the amount given by equation (3.28) without any increase in total project cost from TC(Tc*). A typical breakeven curve is illustrated in FIG. 3-5. For any duration Tc a cumulative capital expenditure less than or equal to C_{BE}(Tc) is acceptable (total cost does not exceed TC(Tc*)). The increase or decrease allowed in C(Tc) is attributable to decreased or increased escalation and finance costs. The shorter the construction duration, of course, the sooner the project can begin production and a return on investment.

3-6 NET PRESENT VALUE

Present worth analysis is most frequently used to determine the present value of future money receipts and disbursements. Net Present Value, NPV, is the present worth of project benefits minus present worth of costs. NPV accounts for all cash flows occurring over the project life, both revenues and the costs required to generate the revenues.

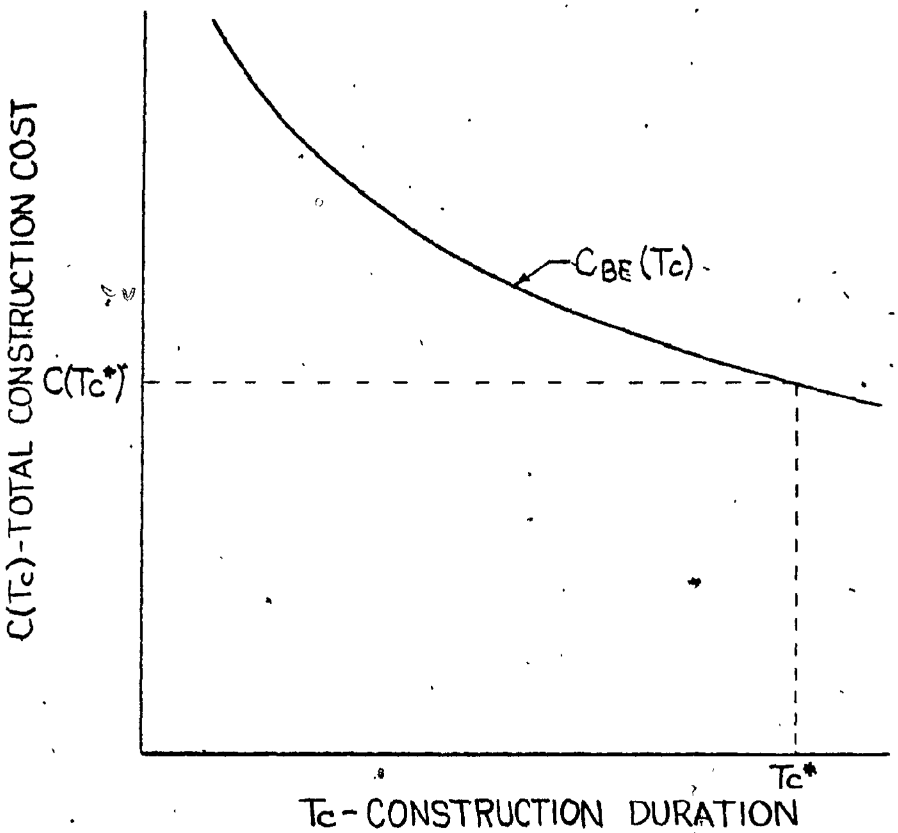


FIG. 3-5
TYPICAL BREAKEVEN CURVE

The cash flow over the entire project is being considered from project start to end of facility operation, Tp.In FIG. 3-6 the project cash flow is presented in terms of constant (time 0) dollars. CF(t) represents the project expenditure cash flow during construction, RF(t) the project inflows during the operating life and EF(t) the constant dollar operating and maintenance costs during the operating life. (EF(t) includes all operating expenses except debt servicing and income tax).

Present worth analysis is to be perceived from the owner's point of view on an after tax cash flow basis. During construction only a portion of the required project cash flow costs come out of the owner's pocket, the rest coming from borrowed funds. As bridge financing has been assumed, the only out of pocket costs incurred by the owner during construction is the equity input cash flow profile based on a constant percentage of the project escalated cash flow requirements. Out of pocket cash flow during construction, CFE(t), is given by;

$$CFE(t)=f \cdot CFc(t) \qquad \text{equation (3.29)}$$

where f is the percentage equity input and CFc(t) the escalated project cash flow during construction.

During the project's operating life it is the escalated, rather than constant dollar, cash flow profiles which are incurred by the owner. Inflation functions, $\theta_R(\tau)$ and $\theta_E(\tau)$, for revenues and expenses, respectively, are established over the project life. The escalated revenue profile RFc(t) is;

$$RFc(t)=RF(t)\ \exp\left(\int_{\tau=0}^{\tau=t} \theta_R(\tau)d\tau\right)$$

equation (3.30)

and similarly escalated expenses profile is;

$$EFc(t)=EF(t)\ \exp\left(\int_{\tau=0}^{\tau=t} \theta_E(\tau)d\tau\right).$$

equation (3.31)

Another cost to the project owner during the operating life is the repayment of the borrowed funds and interest charges accumulated during the construction duration as given by equation (3.17). In this analysis it is assumed the amount owed at the end of construction will be repaid over the entire operating duration at a constant rate. This assumption treats project financing in a similar way to the traditional mortgage of a fixed rate over a set duration. Rate of repayment is constant and equals the sum of the principal and interest payments. Use of continuous flows requires the use of exponential relations. Letting ℓ be the nominal loan interest rate over the project's operating life, the rate of loan repayment, L(t), is:

$$L(t)=L=T\$OEC\cdot ACP$$

equation (3.32)

where

$$ACP=(\ell \exp(\ell\cdot(Tp-Tc)))/(\exp(\ell\cdot(Tp\ Tc)-1).$$

The before tax cash flow, BTCF(t), at any time during the operating life is given by;

$$BTCF(t)=RFc(t)-EFc(t)-L. \qquad \text{equation (3.33)}$$

The after tax cash flow, ATCF(t), is;

$$ATCF(t)=(1-\gamma)\ BTCF(t)-\gamma(A(t)-CCA(t)) \qquad \text{equation (3.34)}$$

where

γ=the combined federal and provincial income tax rate,
A(t)=principal repayment (amortization function),
CCA(t)=capital cost allowance function.

The tax rate is set by government legislation in Canada. In modeling after tax cash flow it has been assumed that taxes will be paid continuously. This is a reasonable assumption given that income taxes are paid monthly by a corporation.

Principal repayment, A(t), is calculated using equation (3.32). The rate of interest accumulation at any point in time, t, is ℓ times the unpaid balance, UPB(t). The unpaid balance, UPB(t), is simply the present worth of all future loan payments;

$$UPB(t)=\int_{t'=t-Tc}^{t'=Tp-Tc} L\ \exp(-\ell \cdot t')dt'$$

$$=(L/\ell)\ (\exp(-\ell \cdot (t-Tc))-\exp(-\ell \cdot (Tp-Tc)))$$

equation (3.35)

so that the rate of interest accumulation, I(t) is;

$$I(t)=\ell \cdot UPB(t).$$

equation (3.36)

Loan repayment, L, is the sum of principal, A(t), and interest, I(t), thus A(t) is;

$$A(t)=L-I(t)$$

$$=L-\ell \cdot UPB.$$

equation (3.37)

In the preparation of accounting statements, the cost of an asset is allocated over its useful life by means of an annual depreciation expense. In computing taxable income, the analogous expense is capital cost allowance, CCA(t). The capital cost allowance is calculated by applying a fixed capital cost rate, d, to a declining capital balance. The original capital balance for the project is the total project cost, TC(Tc), as given by equation (3.23).

The declining balance fixed rate CCA technique gives capital cost allowance for the project as;

CCA(t)=d*TC(Tc)*(1-d)**(t-Tc-1).

equation (3.38)

The owner's cash flow in terms of current dollars is presented in FIG. 3-7 where TAX(t) represents income tax payable based on income less allowable expenses.

Present worth analysis is simply the resolving of future cash flows into equivalent present values to allow comparisons on a comparable basis. Any group of cash flows may be reduced to a single equivalent cash flow by means of the concept of equivalence as presented in Chapter 2. Thus the incomes and expenses for a project may be reduced to a single equivalent cash flow at any point in time which in the following derivation will be defined as the project start.

A major drawback of NPV is the requirement of selecting a minimum attractive rate of return, MARR. MARR is the discount rate applied to future sums in order to obtain present values. A suitable MARR selection is a very complex task, being based generally on the cost of money. Inclusion of risk and uncertainity in MARR selection must not be overlooked.

Three defined costs of money are; one, cost of borrowed money, two, cost of capital and, three, opportunity cost. The highest of these three costs is generally selected as the MARR. Further information regarding MARR selection may be found in "Engineering Economic Analysis" (34).

It is not inconceivable that MARR is a function of time, particularly in the case of borrowed funds. Thus, to allow

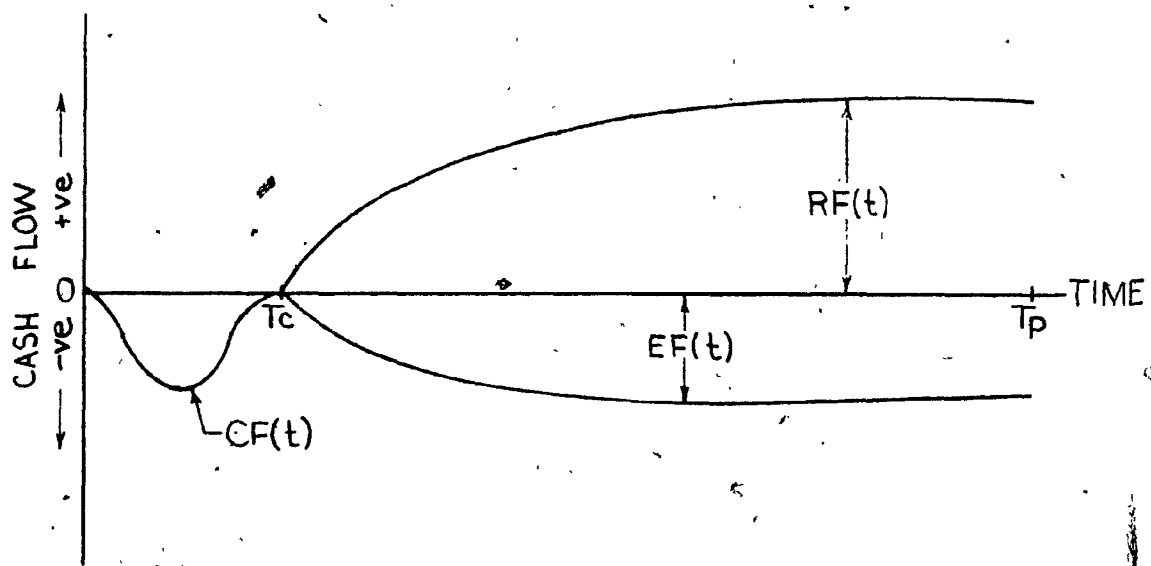


FIG. 3-6
CONSTANT DOLLAR PROJECT
CASH FLOWS

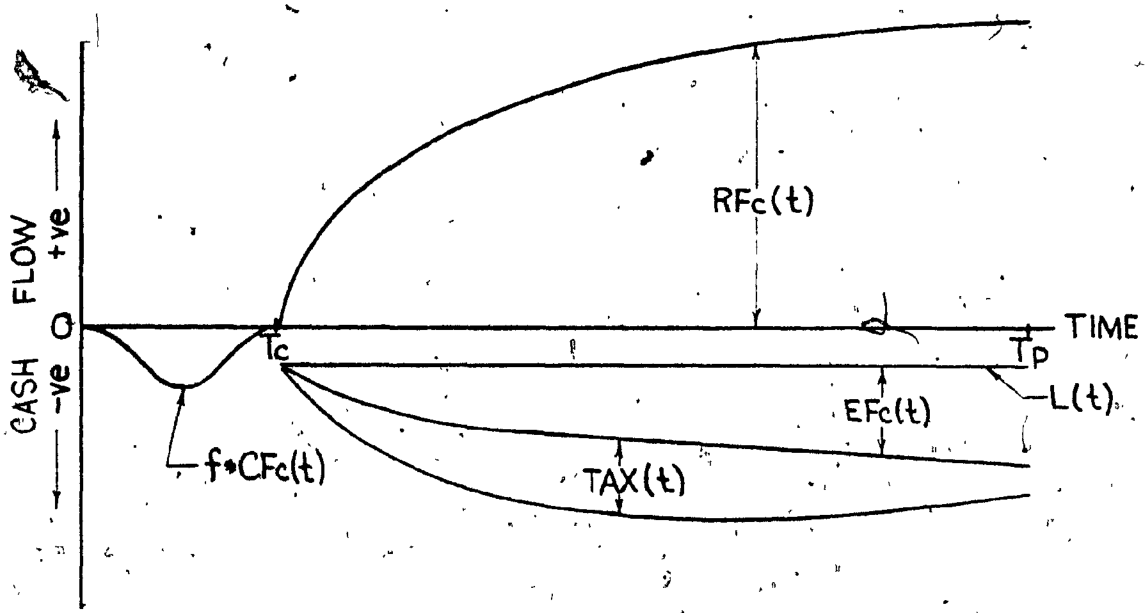


FIG. 3-7
CURRENT DOLLAR OWNER
CASH FLOWS

NPV analysis, a function for the minimum attractive rate of return must be defined over the project duration, $MARR(\tau)$ FIG. 3-8.

The present worth of the equity cash flow during construction, PWECF, is;

$$PWECF=\int_{t=0}^{t=Tc} CFE(t)\ \exp\left(-\int_{\tau=0}^{\tau=t} MARR(\tau)d\tau\right) dt$$

$$=f\int_{t=0}^{t=Tc} CF(t)\ \exp\left(\int_{\tau=0}^{\tau=t} \theta(\tau)d\tau-\int_{\tau=0}^{\tau=t} MARR(\tau)d\tau\right)dt.$$

equation (3.39)

Present worth of cash flows during the operating life at time Tc, the end of construction, PWOCF(Tc) are;

$$PWOCF(Tc)=\int_{t'=t-Tc}^{t'=Tp-Tc} ATCF(t')\ \exp\left(-\int_{\tau=Tc}^{\tau=t'} MARR(\tau)d\tau\right)dt'$$

equation (3.40)

and present worth of the operating cash flows at project start, PWOCF, is;

$$PWOCF=PWOCF(Tc)\ \exp\left(-\int_{\tau=0}^{\tau=Tc} MARR(\tau)d\tau\right).$$

equation (3.41)

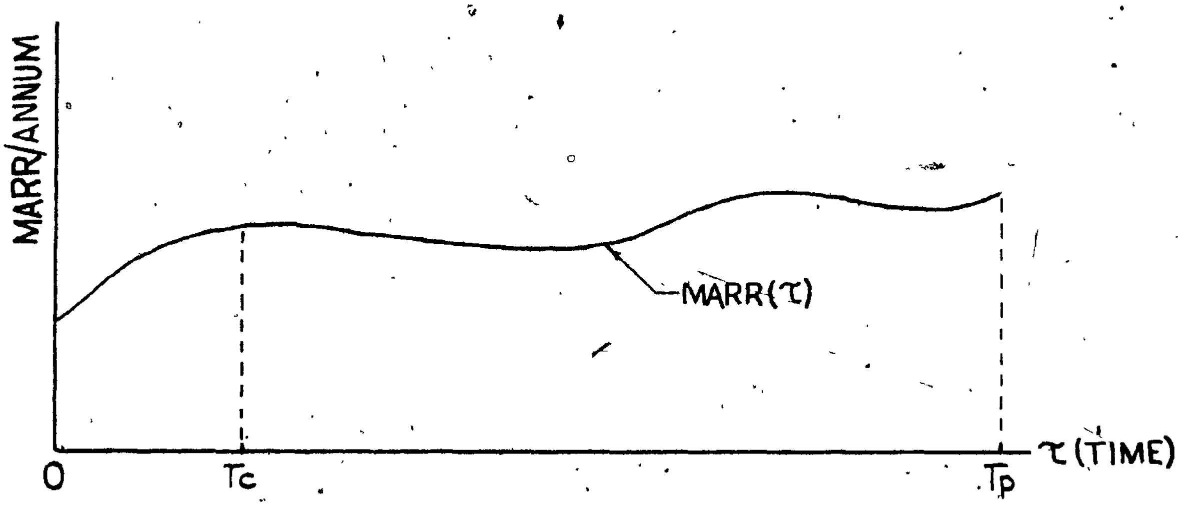


FIG.3-8
PROJECT MINIMUM ATTRACTIVE
RATE OF RETURN PROFILE

Project NPV is then;

$$NPV(Tc)=PWOCF-PWECF. \qquad \text{equation (3.42)}$$

With equation (3.42) the sensitivity of project NPV to various parameters such as capital cost, construction duration, cash flow shape, equity input, escalation rate, interest rate, etc. can be investigated. It is important to note that NPV has been calculated from the owner's equity viewpoint and not from the viewpoint of return on total capital. Secondly, equations (3.39) and (3.41) hold only for the specific project finance arrangements outlined in this section and section 3-3.

3-7 BREAKEVEN CURVE: NET PRESENT VALUE

This development follows the same lines as the breakeven curve for total cost, but here NPV, rather than total cost, will be kept constant. Tc^* is again the established duration with a corresponding net present value of $NPV(Tc^*)$. The breakeven curve will establish by how much $C(Tc)$ can change for any value of Tc such that NPV remains a constant, $NPV(Tc^*)$. The breakeven condition is given by;

$$NPV(Tc)=NPV(Tc^*) \qquad \text{equation (3.43)}$$

where Tc is any construction duration.

Substituting equation (3.24) in equation (3.16) and

(3.23) gives;

$$T\$OEC=C(Tc)\ FW(Tc)$$ equation (3.44)

where

$$FW(Tc)=(1-f)\int_{t=0}^{t=Tc} cf(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau+\int_{\tau=t}^{\tau=Tc} r(\tau)d\tau\right)dt$$

and

$$TC(Tc)=C(Tc)\ FWEQ(Tc)$$ equation (3.45)

where

$$FWEQ(Tc)=(1-f)\int_{t=0}^{t=Tc} cf(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau+\int_{\tau=t}^{\tau=Tc} r(\tau)d\tau\right)dt$$
$$+f\int_{t=0}^{t=Tc} cf(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau\right)dt.$$

Using equations (3.44) and (3.45) in the equations of the previous section allows after tax cash flow to be expressed as;

$$ATCF(t)=XFUNC(t)-C(Tc)\ YFUNC(t)$$ equation (3.46)

where

$$XFUNC(t)=(1-\gamma)\ (RFc(t)-EFc(t))$$

and

$$YFUNC(t)=FW(Tc)\ ACP(1+\gamma(exp(-l\cdot(Tp-Tc))-exp(-l\cdot(t-Tc))))$$
$$+\gamma FWEQ(Tc)\ d(1-d)^{**}(t-Tc-1).$$

Using equation (3.46) in equation (3.41) gives the present worth of project operating cash flows at the project start as;

$$PWOCF=exp(-\int_{\tau=0}^{\tau=Tc} MARR(\tau)d\tau)\int_{t'=Tc}^{t'=Tp-Tc} XFUNCEXP(t')dt'$$
$$C(Tc)\ exp(-\int_{\tau=0}^{\tau=Tc} MARR(\tau)d\tau)\int_{t'=Tc}^{t'=Tp-Tc} YFUNCEXP(t')dt'$$

equation (3.47)

where

$$XFUNCEXP(t')=XFUNC(t')\ exp(-\int_{\tau=Tc}^{\tau=t'-Tc} MARR(\tau)d\tau)$$

and

$$YFUNCEXP(t')=YFUNC(t')\ exp(-\int_{\tau=Tc}^{\tau=t'-Tc} MARR\ (\tau)d\tau).$$

Substituting equation (3.24) in equation (3.39) gives the present worth of cash flows during construction as;

$$PWECF=C(Tc)\ f\int_{t=0}^{t=Tc} ECFV(t)dt$$

equation (3.48)

where

$$ECFV(t)=cf(t)\ \exp\left(\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau-\int_{\tau=0}^{\tau=t}MARR(\tau)d\tau\right).$$

Substituting equation (3.47) and (3.48) in equation (3.42) and then placing this in equation (3.43) and rearranging for capital cost gives;

$$C_{BE}(Tc)=\left(\exp\left(-\int_{\tau=0}^{\tau=Tc}MARR(\tau)d\tau\right)\int_{t'=Tc}^{t'=Tp-Tc}XFUNCEXP(t')dt'-NPV(Tc^{*})\right)/$$
$$\left(f\int_{t=0}^{t=Tc}ECFV(t)dt+\exp\left(-\int_{\tau=0}^{\tau=Tc}MARR(\tau)d\tau\right)\int_{t'=Tc}^{t'=Tp-Tc}YFUNCEXP(t')dt'\right)$$

equation (3.49)

where $C_{BE}(Tc)$ is the breakeven capital cost for duration Tc.

Equation (3.49) allows breakeven capital cost to be established on a net present value basis. When NPV is kept a constant, it can be not too strongly argued that, the project internal rate of return remains constant.

3-8 SUMMARY

The project level or Macro Models developed in this chapter were total project cost TC(Tc), net present value from the project owner's equity viewpoint NPV(Tc) and the capital expenditure breakeven curves $C_{BE}(Tc)$ based on constant total cost and constant net present value. Each of these models can be used to evaluate variations in project level scheduling and engineering decision variables and/or as a means of comparing project alternatives.

CHAPTER 4

ANALYTICAL EVALUATION OF MACRO MODELS

In this Chapter the Macro Models developed in the previous Chapter are analyzed using example projects. Numerical analysis allows observation of how project level performance measures react to changes in project level decision variables. Investigation allows some general observations and simplifying conclusions to be drawn. Of particular interest is the relative insensitivity of project level performance measures to cash flow profile shape. Cash flow is modeled by the well known beta distribution.

4-1 CASH FLOW MODEL

Numerous mathematical formulae have been suggested for project capital expenditure modeling (4). Functions suggested to date all have inherent disadvantages or shortcomings. The ideal mathematical model of the S-curve (capital expenditure) or cash flow should satisfy each of the following criteria:

1) be simple in application and easily understood,
2) provide versatility, model actual projects, limiting cases and end points realistically,
3) have parameters that can be easily computed,
4) be able to withstand rigorous statistical testing and
5) be compatible with NPV and IRR calculations.

In this paper the beta function has been selected to model the constant dollar cash flow. The beta function is a very flexible distribution allowing modeling of a wide variety of shapes through parameter manipulation (see FIG. 4-1). The constant dollar cash flow is represented by;

$$CF(t)=(1/B)\ (1/Tc^{(q-1)})\ t^{(p-1)}\ (Tc-t)^{(q-p-1)} \qquad \text{equation (4.1)}$$

where q and p are the beta function parameters, Tc the project construction duration, t any time between construction start and finish and (1/B) is given by;

$$(1/B)=\Gamma(q)/(\Gamma(p)\Gamma(q-p)). \qquad \text{equation (4.2)}$$

The cash flow equation applies only for p and q-p positive and will produce a unimodal generally skewd bell shaped curve profile when $p>1$ and $q>p+1$.

The beta model of equation (4.1) meets all the criteria previously stated except that it cannot model project cash flows that are multimodal in nature. Proposed, but not examined in detail, is the summation of beta curves so as to produce multimodal functions. The question of multimodality has not been considered in any proposed model function to date (4).

Familiarity with the beta function can be obtained through consultation with most statistical texts (31).

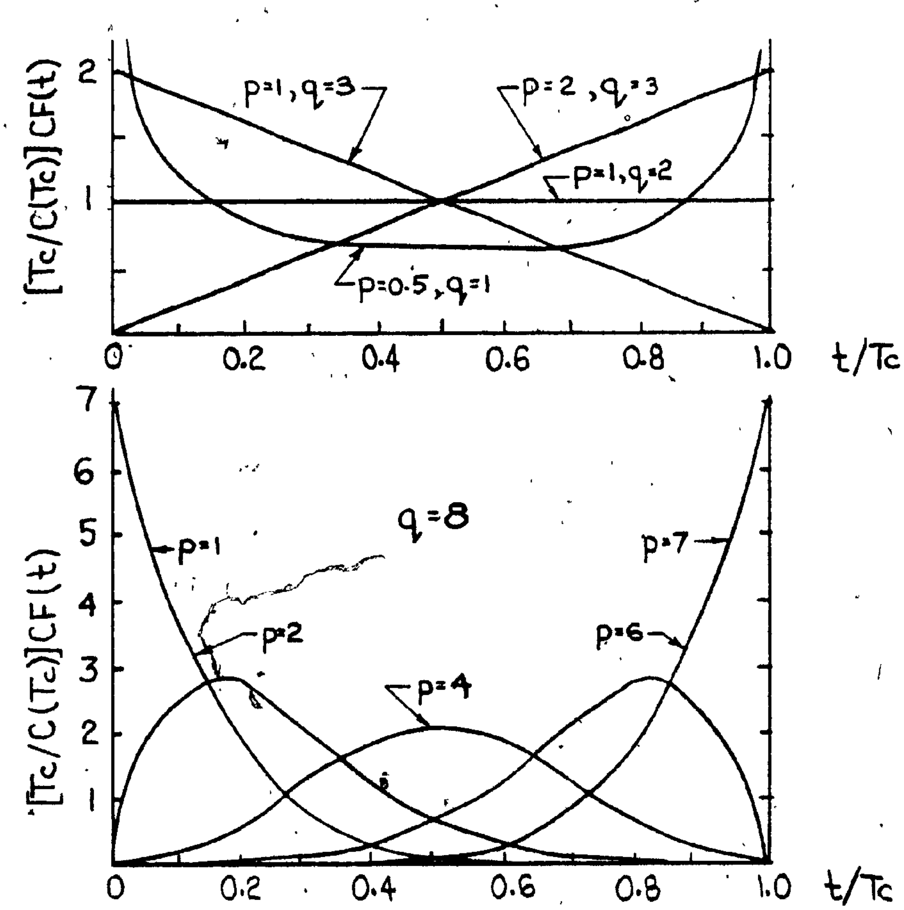


FIG.4-1
VERSATILITY OF THE BETA DISTRIBUTION AS A MODEL FOR CASH FLOW

However, the fitting of the beta distribution to a set of data is not always a topic covered and is therefore included in an appendix to this Chapter.

De la Mare (4) suggests that specific project types will maintain specific cash flow profile shapes. Thus through analysis of existing projects beta parameters could be obtained which describe the cash flow profile shape for a specific project type. When a similar proposed project is to be analyzed the beta parameters calculated from past projects could then be used to establish the cash flow profile for the proposed project.

4-2 TOTAL COST ANALYSIS

The total cost performance measure can give some very useful insights into the effects of project decision variables. Variability of cash flow shape is important as it corresponds to the simulation of various planning strategies such as early start, late start, changes in activity sequencing and timing of procurements. Other important variables are construction duration, inflation and interest rate scenarios and the equity input percentage.

Project total cost is given by equation (3.23). Although arbitrary functions could be assumed for $\theta(\tau)$ and $r(\tau)$ in the equation, analysis here is confined to a linear representation. This restriction allows observations of total cost under linearly increasing, linearly decreasing and constant rate inflation profiles. This is a realistic assumption given that the future is uncertain and that in less volatile times inflation can indeed be well represented by a linear function, since interest lies in trends rather than actual fluctuations over small time periods.

The inflation rate will be assumed given by;

$$\theta(\tau)=\theta o+\Delta\theta\tau \qquad \text{equation (4.3)}$$

where θo is the rate of inflation at the project start (base rate) and Δθ the yearly rate of inflation rate increase over the construction duration, $0\leq\tau\leq Tc$.

Project interest rate will be assumed correlated to the inflation function by the relation;

$$r(\tau)=r_o+\theta(\tau) \qquad \text{equation (4.4)}$$

where r_o is some fixed real rate of interest. The real rate is assumed to account for all the costs of borrowing except inflation.

The project total cost, equation (3.23), calls for the integration of equations (4.3) and (4.4). Integration of the inflation function gives;

$$\int_{\tau=0}^{\tau=t}\theta(\tau)d\tau = \int_{\tau=0}^{\tau=t}(\theta o+\Delta\theta\tau)d\tau$$

$$=t(\theta o+0.5\Delta\theta t) \qquad \text{equation (4.5)}$$

while integration of the interest rate function gives;

$$\int_{\tau=t}^{\tau=Tc} r(\tau)d\tau = \int_{\tau=t}^{\tau=Tc} (r_o+\theta o+\Delta\theta\tau)d\tau$$

$$=(Tc-t)(r_o+\theta o+(\Delta\theta/2)(Tc+t)). \quad \text{equation (4.6)}$$

Equations (4.5) and (4.6) can now be substituted into equation (3.23).

A simple example is presented. A project having a constant dollar capital expenditure of 10 million dollars is to be constructed over a 5 year period. The constant dollar capital cost is assumed to be spread uniformly over the construction duration. Inflation at project start is 10% and estimated to remain constant. The fixed real rate of interest is set at 4%, thus making the nominal interest rate equal to 14%. Equity input percentage during construction is 10%.

$Tc=5$ years
$C(Tc)=\$10{,}000{,}000$
$CF(t)=C(Tc)/Tc=\$2{,}000{,}000$ per year
$\theta o=10\%$ per year
$\Delta\theta=0\%$ per year
$r_o=4\%$ per year
$f=10\%$

Using equation (4.5) in equation (3.21) gives the project escalation cost, $E(Tc)$;

$$E(Tc)=\int_0^{Tc} (C(Tc)/Tc)\ \exp(\theta t)dt-C(Tc)$$

$$=(C(Tc)/\theta Tc)(\exp(\theta Tc)-1)-C(Tc).$$

Substituting the above values gives;

E(Tc)=$2,974,425.

Substituting equations (4.5) and (4.6) into equation (3.22) gives the project financing costs, F(Tc);

$$F(Tc)=TC-C(Tc)-E(Tc)$$

$$=f\frac{C(Tc)}{\theta Tc}(e^{\theta Tc}-1)+(1-f)\frac{C(Tc)}{(\theta-r)Tc}(e^{(\theta-r)Tc}-1)-\frac{C(Tc)}{\theta Tc}(e^{\theta Tc}-1).$$

Upon substitution of above values financing cost is;

F(Tc)=$4,749,432.

Total project cost, TC(Tc), is given by equation (3.18);

TC(Tc)=$10,000,000+$2,974,425+$4,749,432

=$17,723,857.

In the following work CF(t) in the total cost equation will be modeled by equation (4.1).

The relationship between total cost and construction duration is shown in FIG. 4-2. A uniform expenditure model (p=1,q=2) is analyzed. Capital cost in time 0 dollars is $1,000,000. Inflation at the project start is 10% and allowed to increase at various rates, $\Delta\theta$. The fixed real rate of interest is set at 4% and equity input at 10%.

From FIG. 4-2 it can be seen that the longer the project duration the greater the project total cost due to increases in both escalation and financing charges. Further, the combined costs of escalation and financing can exceed the constant dollar costs by a factor of 2 and 3 for projects of longer duration. It is also noted that the greater the rate of inflation increase the greater the total cost. These results are as expected; longer exposure to escalation and financing increases costs and higher inflation rates mean higher escalation costs which must be financed at correspondingly higher rates of interest. Extension of this argument can be carried to the base inflation rate, the higher the base rate of course the higher the total cost. A further observation that can be made is that a higher real rate of interest results in higher financing costs which in turn cause a higher total project cost.

In FIG. 4-3 a uniform cash flow profile is again assumed for a $1,000,000 capital expenditure project lasting five years. Base inflation is again 10% and various rates of inflation increases are provided. The real rate of interest is 4% and the equity input fraction is allowed to vary.

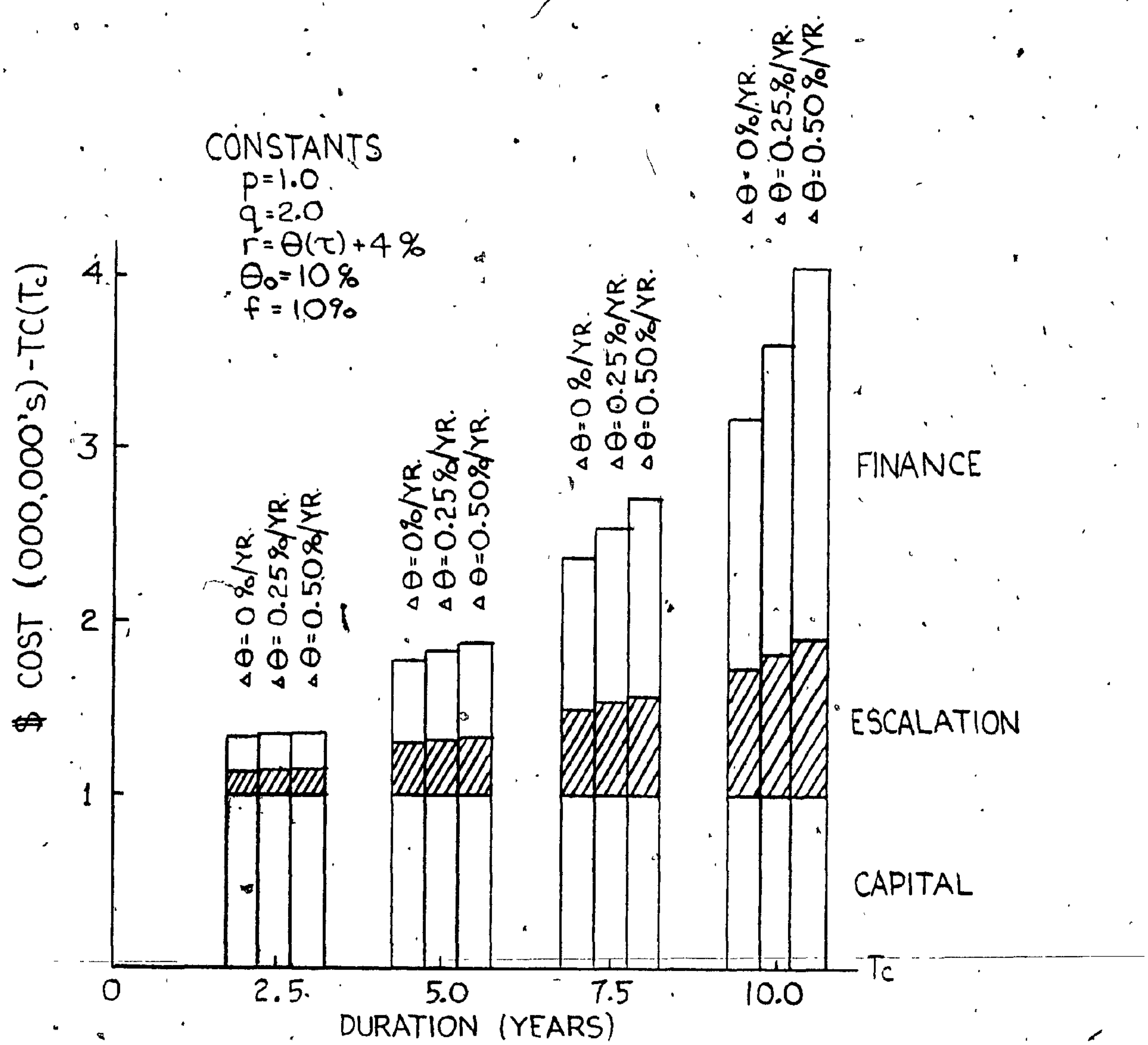


FIG. 4-2
TOTAL COST: DURATION AND
RATE OF INFLATION VARIABLE

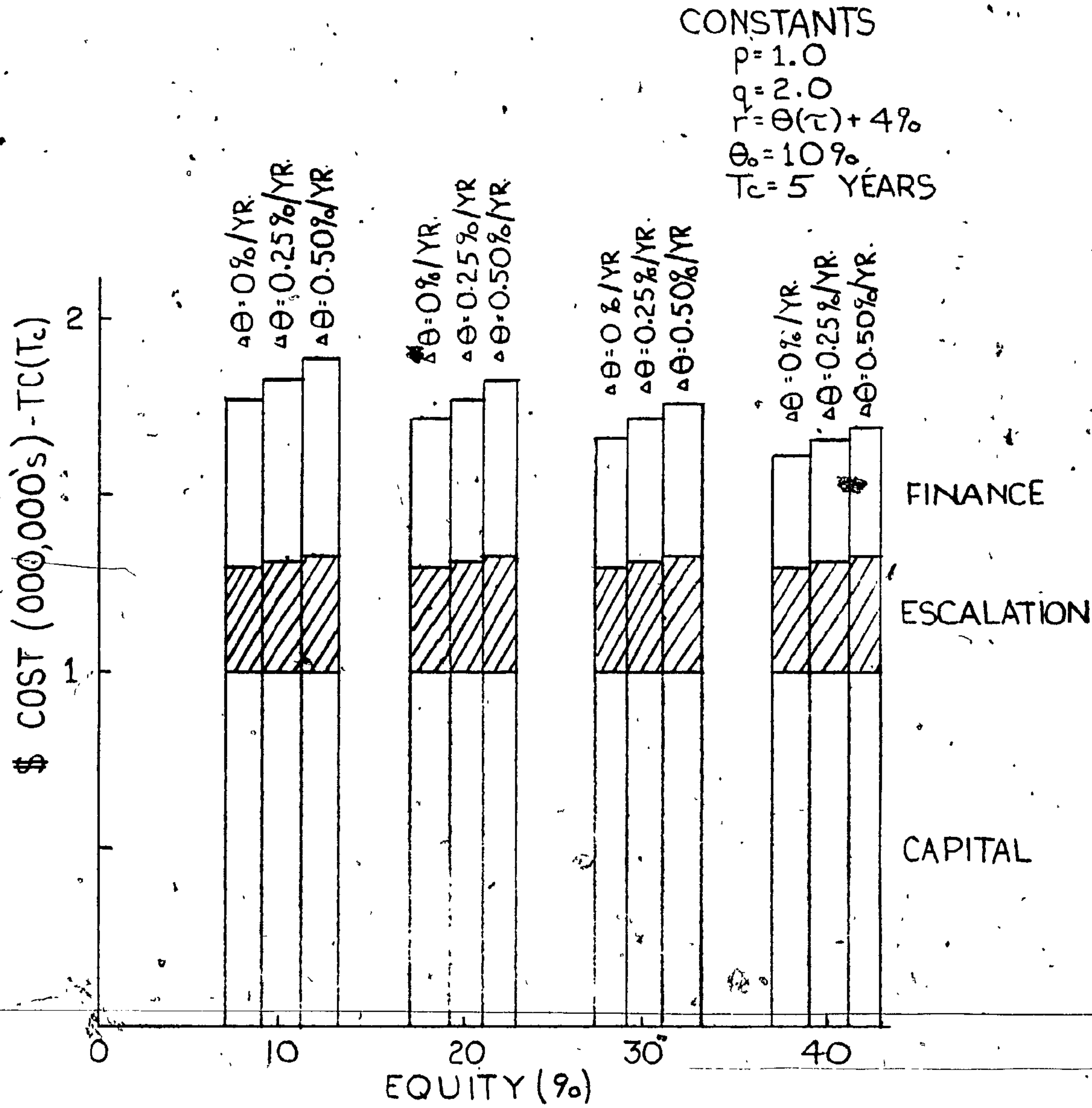


FIG. 4-3
TOTAL COST: EQUITY AND
RATE OF INFLATION VARIABLE

FIG. 4-3 shows that a greater equity percentage reduces the costs of financing thereby reducing project total cost. The figure once again shows that a higher rate of inflation increase results in a higher total project cost.

Two cash flow profiles having equal magnitude modes occurring at a 35% duration difference will be analyzed to simulate early and late strategies of scheduling and to ascertain sensitivity of total cost to cash flow profile shape. The early and late strategy curves represent changes in the actual logic of the project network so as to either speed up or slow down, respectively, the rate of construction. Construction duration remains constant and it follows that the critical path will remain unchanged. In FIG. 4-4 the skewed right curve is designated the early strategy curve ($p=2.79$, $q=7.52$) and the skewed left curve ($p=4.73$, $q=7.52$) the late strategy curve. These curves were selected as they represent a substantial change in the cash flow profile as evidenced by the diagram.

The sample project is again assumed to have a capital expenditure estimate of one million dollars. Base escalation is 10% and remains constant over any construction duration. Nominal interest rate is fixed at 14% while equity is set at 10%.

FIG. 4-5 compares the total cost for each schedule strategy type versus construction duration. An early start strategy minimizes exposure to escalation at a cost of longer exposure to financing while the late strategy maximizes

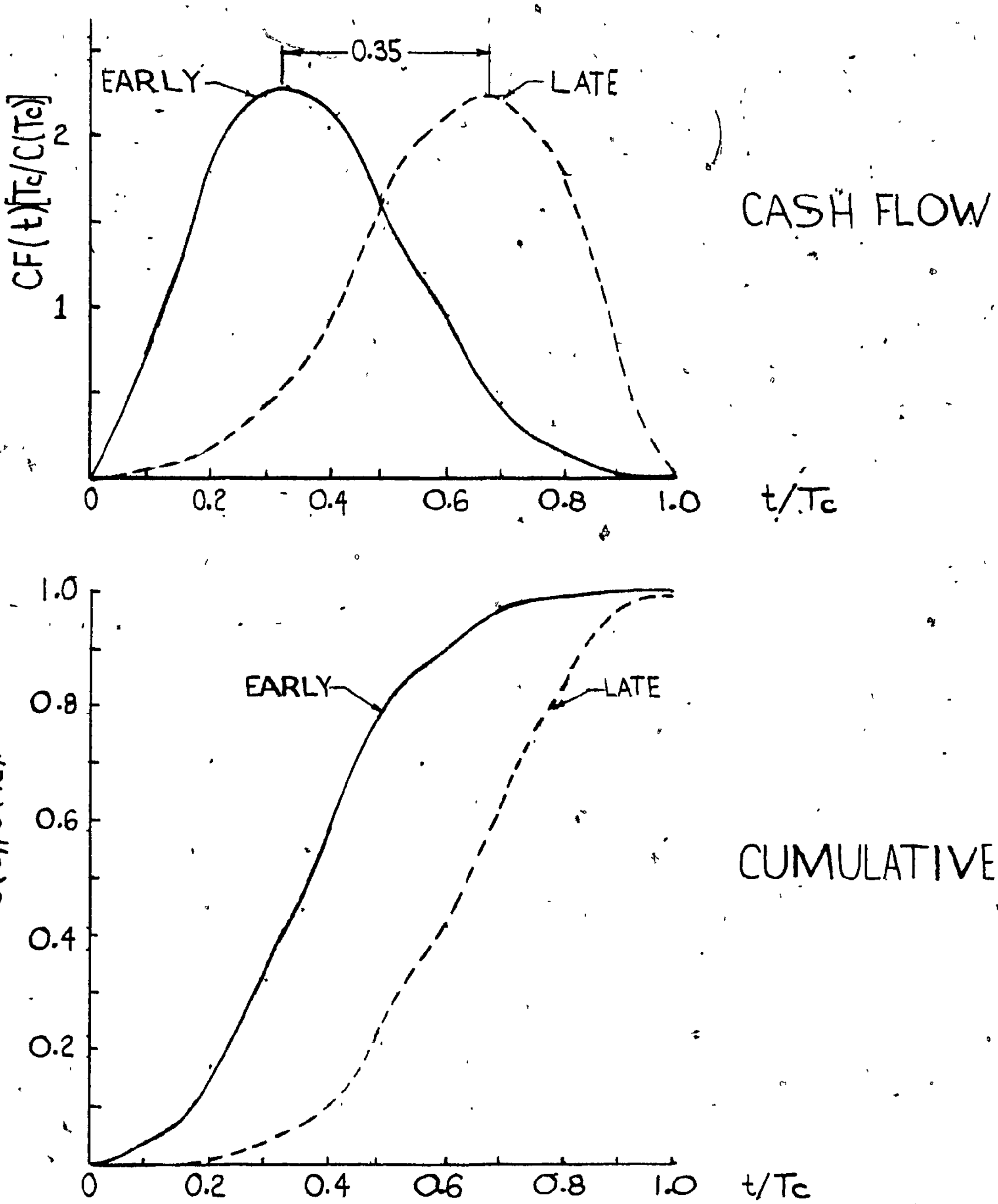


FIG. 4-4
EARLY AND LATE STRATEGIES
CONSTANT DOLLAR PROFILES

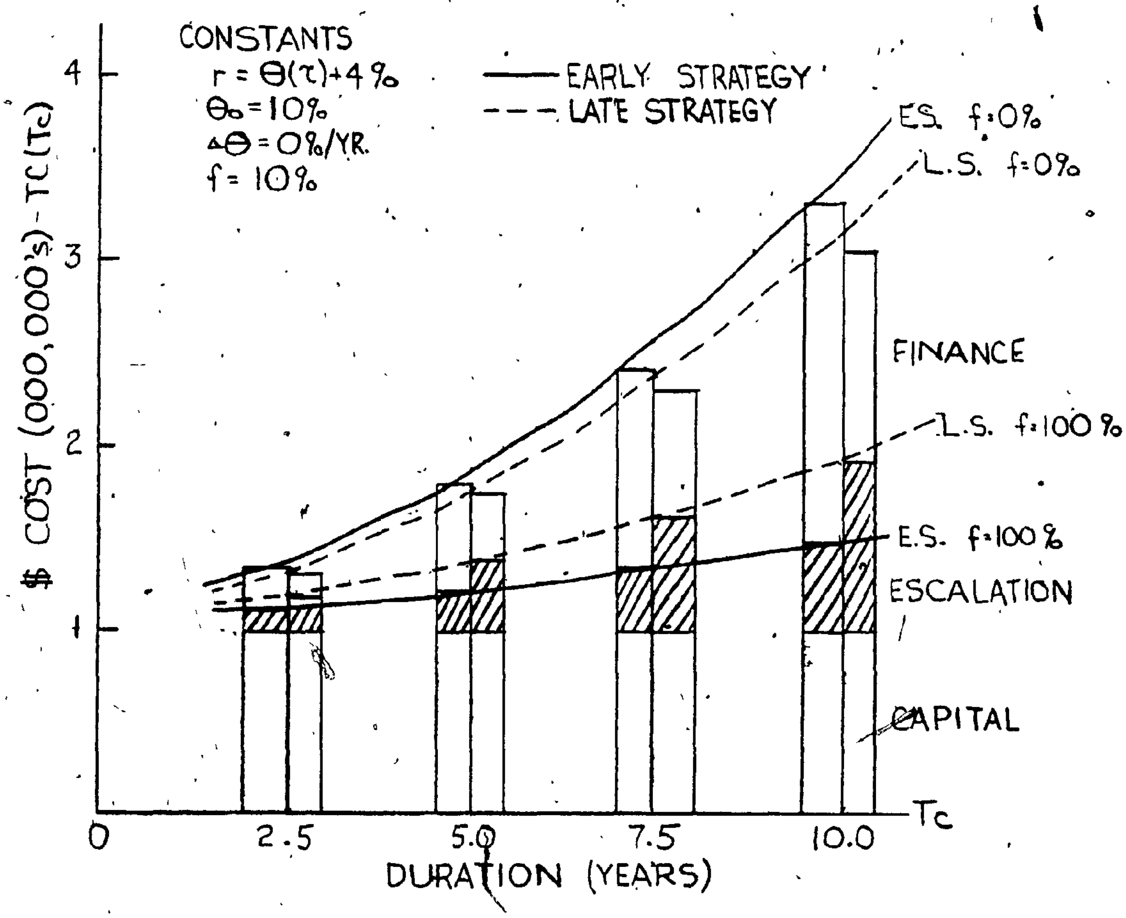


FIG. 4-5
TOTAL COST: EARLY VS. LATE STRATEGY DURATION VARIABLE

escalation exposure while minimizing the financing costs. This can be checked by comparing the magnitudes of escalation and financing costs for each strategy in the figure.

In this analysis the finance rate is a function of the rate of inflation, always being greater than inflation by a fixed real rate. Under this condition it may be generally concluded that under normal project financing agreements a late strategy will produce a lower total project cost. However, as also illustrated in FIG. 4-5, the possibility exists for late strategy total costs to exceed early strategy costs when the equity percentage input is large (f=100%).

An interesting observation is that any cumulative expenditure profile lying between the two cumulative curves of FIG. 4-4 will have a total cost lying between the total costs of the selected early and late start strategies. This can be put to use as illustrated by way of example of data obtained for a 231 million dollar (constant dollars) project. The actual estimated cumulative curve could not be fitted by a beta curve as it was multimodal in nature. However, the estimated curve could be bounded by two unimodal beta curves as shown in FIG. 4-6. Construction duration is 5 years, escalation and interest rates are constant at 10% and 15% respectively and equity input is fixed at 25%.

For the curve given by the beta parameters p=3.10 and q=6.35 the total cost was calculated as $399,004,200 while for the curve p=1.40 and q=2.90 calculated total cost is

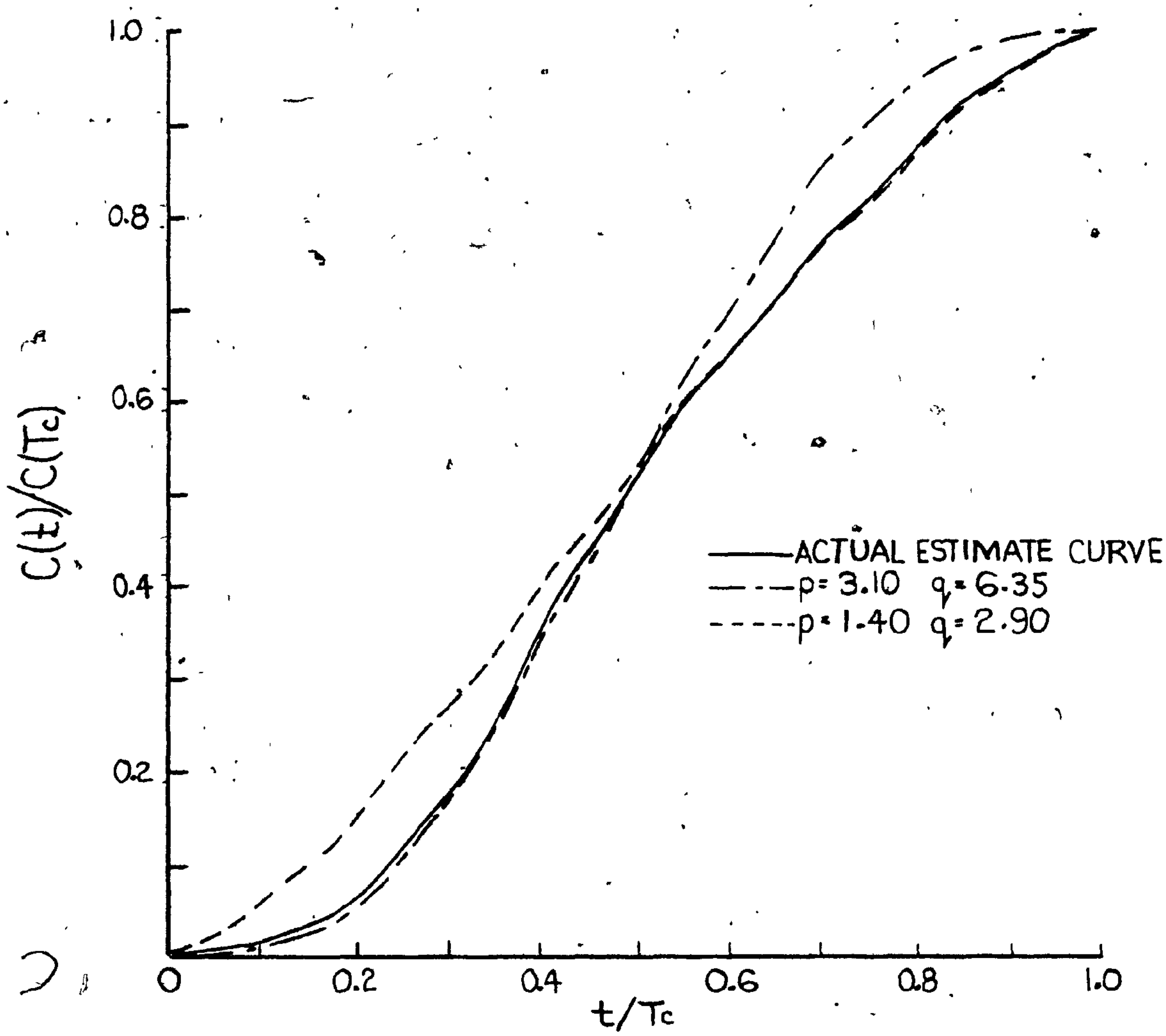


FIG. 4-6
BOUNDING ACTUAL ESTIMATED CUMULATIVE CURVE OF A $231 MILLION PROJECT

\$399,809,300. Thus for the actual multimodal estimated cumulative curve, under the given conditions, the total cost estimate will lie in the range of 399-400 million dollars.

To investigate the effects of cash flow shape further, total cost for the best average fit, best fit based on cash flow mode and uniform cash flow profiles were also considered for the \$231,000,000 project, FIG. 4-7. Under the original project conditions already given the total costs were found to be;

Best average fit	\$398,146,300
Best fit based on mode	\$401,482,000
Constant cash flow	\$399,412,000

all of which are within an acceptable error of the 399-400 million range previously established. The wide range of cash flow profiles, yet similar total costs, tends to suggest that for the purposes of calculating total cost estimates, cash flow profile shape is not all that significant.

Further investigation on importance of cash flow shape was carried out through consideration of the early and late strategies of FIG. 4-4. Numerous computer runs were performed with these cash flows with the results of one typical run as follows;

$f=10\%$,
$\theta o=10\%$ per year
$\Delta\theta=0.5\%$ per year
$r=\theta(\tau)+4\%$

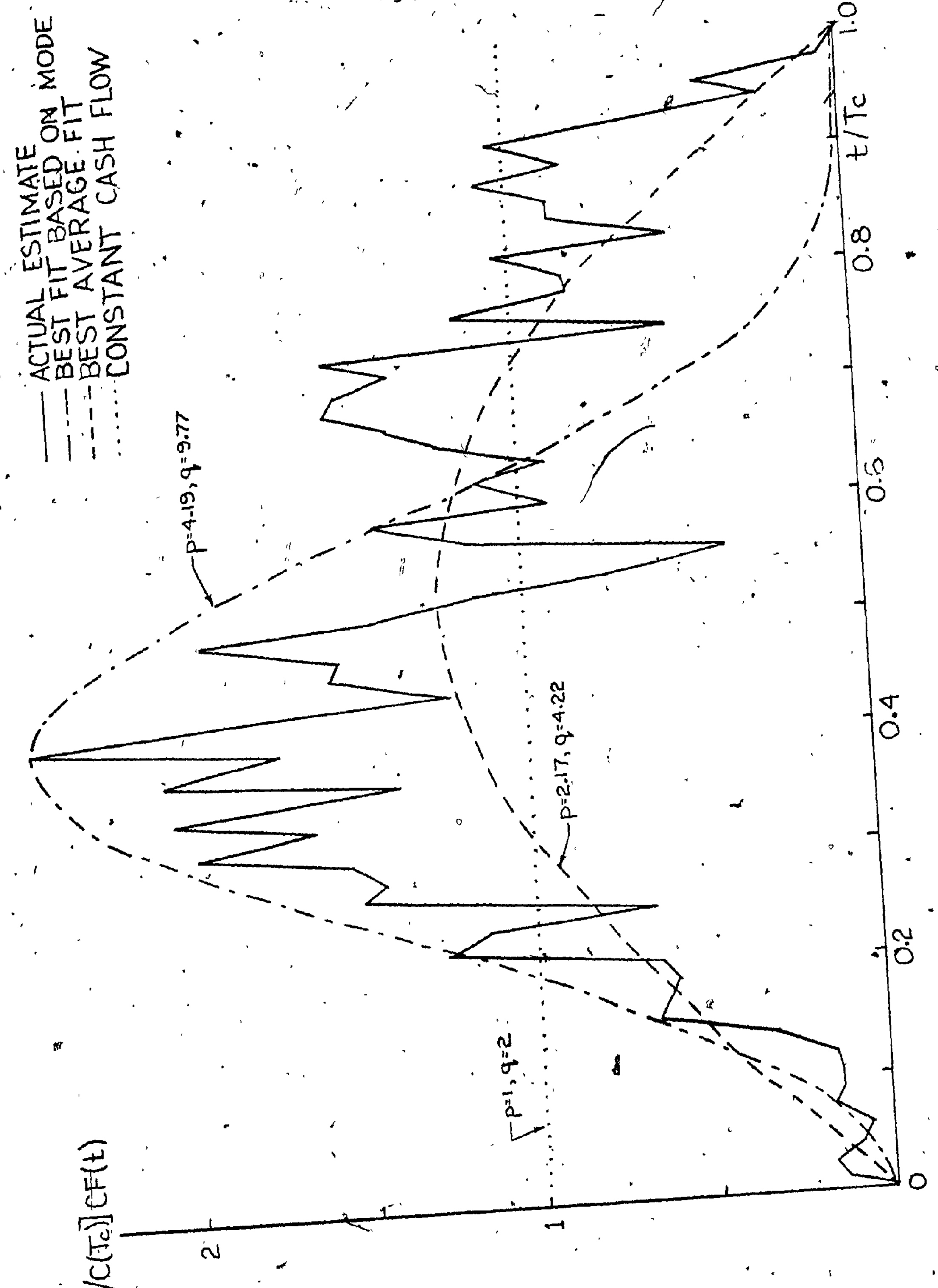


FIG. 4-7
MODELING ACTUAL ESTIMATED CASH FLOW OF A $231 MILLION PROJECT FOR TOTAL COST

TABLE 4.1

EARLY vs. LATE STRATEGY TOTAL COST RESULTS

DURATION YEARS	TOTAL COST TC(Tc) EARLY STRATEGY	LATE STRATEGY	PERCENT DIFFERENCE
2	$ 1,275,675	$ 1,257,820	1.4
4	$ 1,663,021	$ 1,614,812	3.0
6	$ 2,215,972	$ 2,115,835	4.7
8	$ 3,018,455	$ 2,830,306	6.6
10	$ 4,202,892	$ 3,865,734	8.7
12	$ 5,981,555	$ 5,391,574	10.9
14	$ 8,699,907	$ 7,678,042	13.3
16	$12,929,160	$11,167,390	15.8

where

$$\text{PERCENT DIFFERENCE} = \frac{\$\text{EARLY STRATEGY TC(Tc)} - \$\text{LATE STRATEGY TC(Tc)}}{\$\text{LATE STRATEGY TC(Tc)}} \cdot 100.$$

Based on the above figures and other computer runs it appears that for a short to medium duration project the accuracy of cash flow profile is irrelevant in the calculation of total cost. (It is of course important for averaging the availability of funds). Thus a straight line assumption would produce a total cost extremely close to that found by using an accurate cash flow profile.

Results of the above runs also indicate that as duration increases so does the percent difference calculation. This suggests that the shape of the cash flow profile assumes more significance under longer duration projects. However, using the straight line assumption for the 16 year duration produces a total cost calculation of $12,180,650 which gives a percent difference of 6.1% from the early start value and a 9.1% difference from the late start value. Thus it may be argued that even over longer durations there is a relative insensitivity of total cost to cash flow shape.

Results indicate that if the actual project cumulative expenditure curve lies between the two bounds defined by the early and late start strategies, FIG. 4-4, that the cash flow can be modeled effectively as a uniform flow. Since the variation in the cash flows of FIG. 4-4 is quite large it may be stated that for the purpose of total cost calculation project cash flow may be represented as a uniform flow.

With the relative insensitivity of total cost to cash flow shape established it is interesting to examine the assumption of taking the entire project capital expenditure, C(Tc), as occurring at one point in time (an "impulse" expenditure). Foregoing the actual steps required, the total cost for "impulse" expenditure is given by;

$$TC(Tc)=((1-f)\exp((r_o+\theta o)Tc-r_o t_I+0.5\Delta\theta Tc**2) +f\ \exp(t_I(\theta o+0.5\Delta\theta t_I)))*C(Tc) \qquad \text{equation (4.7)}$$

as derived from equation (3.23) for total cost and equations (4.5) and (4.6) assuming linear inflation. In equation (4.7) t_I is the time of occurrence of the "impulse" flow, C(Tc).

The "impulse" equation is used on the previous example of a $231 million project having a 5 year construction period. Inflation, interest and equity are constant at 10%, 15% and

25% respectively. C(Tc), the "impulse" flow is placed at 50% of the project duration, t_I=2.5 years. Total cost as given by equation (4.7) is;

$$TC(Tc)=0.25\exp(0.1\cdot 2.5)+0.75\exp(0.75-(2.5\cdot 0.05))\cdot C(Tc)$$
$$=\$397,326,080$$

which is a reasonably accurate estimate of the 399-400 million dollar total cost range previously determined.

Analysis of other cash flow profiles is supportive of placement of C(Tc) as an "impulse" flow occurring at 50% project duration for the purpose of obtaining a reasonable estimate of total cost. (Some evidence suggests a more accurate calculation if the "impulse" is placed at the centroid of the actual cash flow. However, determination of the centroid requires creation of the actual cash flow which would negate any simplification due to "impulse" modeling). "Impulse" modeling makes calculation of total project cost, and its components (escalation and financing costs), a relatively simple task so that the only reason for ascertaining the shape of the cash flow is to verify that any constraints imposed on the availability of funds is not exceeded and to allow for the arrangement of needed funds as required.

4-3 BREAKEVEN CURVE ANALYSIS: TOTAL COST

Points on the breakeven curve show by how much project capital expenditure, C(Tc), can be allowed to increase for any duration, given that project total cost is to remain fixed at TC(Tc*). Tc* is the established construction duration of the project. The breakeven criteria is to find what increase in the value of C(Tc) can be absorbed without changing project total cost. In the following, the assumptions used for total cost with regards to linear escalation and financing rate functions apply.

The example project presented in the previous section is used again to calculate a breakeven point. Capital expenditure for a 5 year duration was 10 million dollars. In this example the breakeven value of capital expenditure is to be found when the construction duration is crashed from 5 to 4.5 years:

$$Tc=4.5 \text{ years}$$
$$C_{BE}(Tc)=C_{BE}(4.5)$$
$$CF(t)=C_{BE}(4.5)/Tc$$
$$\theta o=10\%/\text{year}$$
$$\Delta\theta=00\%/\text{year}$$
$$r_o= 4\%/\text{year}$$
$$f=10\%$$

The escalation cost for Tc=4.5 years is;

$$E(Tc)=CF(t)\int_{t=0}^{t=Tc} e^{\theta ot}\,dt- C_{BE}(Tc)$$

$$=0.2629\ C_{BE}(Tc).$$

using equation (4.5) in equation (3.21). Cost of financing is given by equation (3.22) using equations (4.5) and (4.6);

$$F(Tc)=(1-f)\ CF(t)\int_{t=0}^{t=Tc}(e^{((\theta o+r_o)Tc-r_o t)}-e^{\theta t})dt$$

$$=0.4099\ C_{BE}(Tc).$$

Equation (3.18) gives total cost;

$$TC(Tc)=C_{BE}(Tc)(1.0+0.2629+0.4097)$$

$$=1.6728\ C_{BE}(Tc).$$

From the results of the example in the previous section;

$$Tc^{*}=5 \text{ years}$$
$$TC(Tc^{*})=\$17,723,857$$

and using the total cost breakeven criteria of equation (3.27);

$$1.6728\ C_{BE}(Tc)=\$17,723,857$$

$$C_{BE}(Tc)=\$10,595,428.$$

Thus, if construction duration is crashed from 5 to 4.5 years, capital expenditure can increase by $595,428 while maintaining project total cost, C(Tc*), at $17,723,857.

Breakeven curves for various expected construction durations, Tc*, are shown in FIG. 4-8. As before, cash flow is uniform (p=1.0,q=2.0) with a capital cost of $1,000,000. Nominal interest and inflation are constant at 14% and 10% respectively while equity bounds of 0% and 100% are examined.

In FIG. 4-8, the difference between the breakeven curve and $1,000,000 is the allowable change in C(Tc) without causing any increase in project total cost as calculated for Tc*. From the figure it can be noted that the longer the established construction duration, Tc*, the steeper the slope of the breakeven curves, therefore the greater the allowable increase in capital expenditure. As an example from FIG. 4-8 for the f=0% case, on a normalized time basis, a 10% reduction in construction duration for the Tc*=5.0 year curve allows constant dollar capital expenditure to be increased by 6.2% while a 10% duration reduction for the Tc*=10 year curve allows an increase of 12.9%. However in terms of actual time units, allowable cost increases are observed to be relatively insensitive to the project construction duration. A constant dollar capital expenditure increase of 12.88% is allowed when a 10 year project is reduced by one year to 9 years while a 12.81% increase is allowed when a project of duration Tc*=5 years is reduced to 4 years. Thus, although it can be

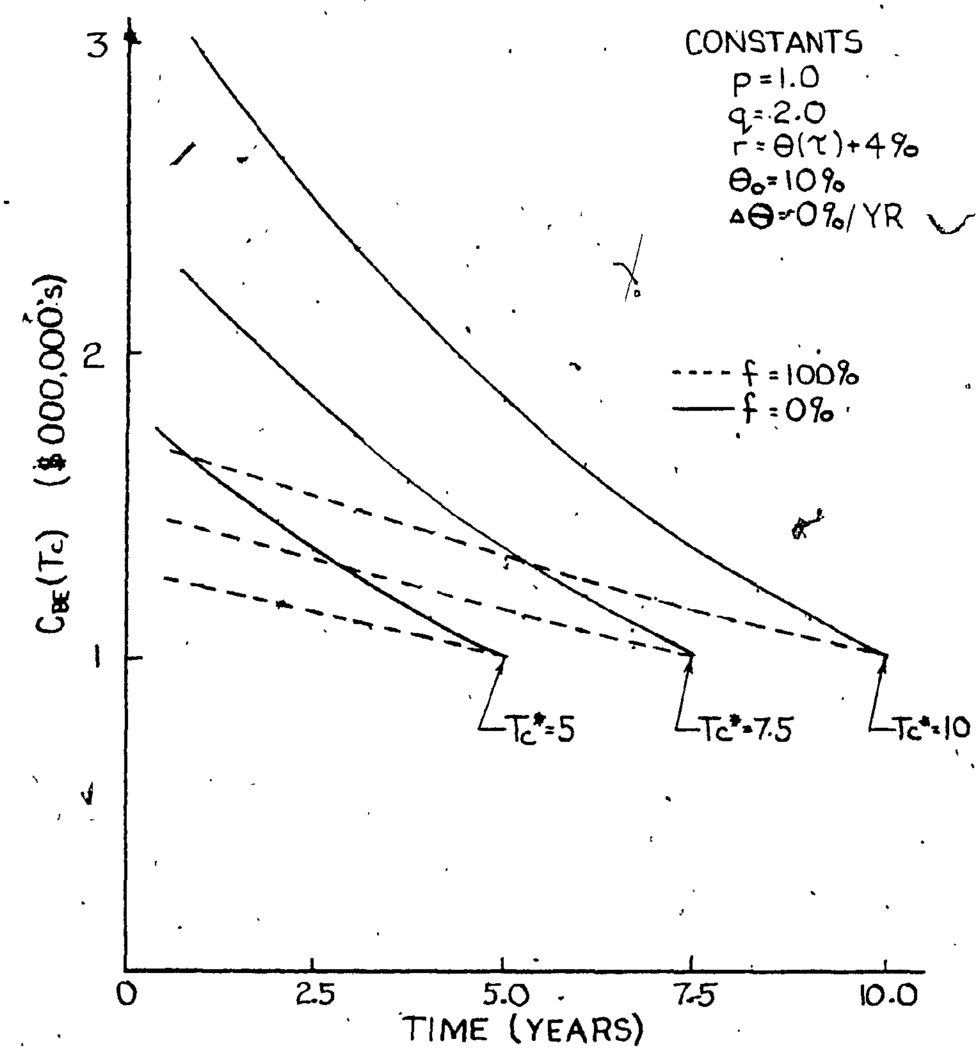


FIG. 4-8
TOTAL COST BREAKEVEN CURVES
DURATION (T_c^*) VARIABLE

concluded that the longer the established construction duration, Tc*, the steeper the slope of the breakeven curve; the resulting increase in steepness does not appear to be all that significant when duration reductions are considered in terms of real time units rather than normalized time.

FIG. 4-9 uses the same project conditions as FIG. 4-8, except that the rate of inflation increase, $\Delta\theta$, is allowed to vary. From the figure, the greater the rate of increase in inflation rate the steeper the slope of the breakeven curve. As expected, the change in steepness of a breakeven curve for a given $\Delta\theta$ is dependent on Tc*, the larger Tc* the greater the slope. This relationship also holds for the base inflation (θo) and fixed rate of interest (r_o) terms, the greater the value the greater the potential for crashing without incurring greater total cost.

Both FIG. 4-8 and FIG. 4-9 show that a greater equity percentage reduces the slope of the breakeven curve. This is expected as a higher equity input percentage reduces the financing costs whereas a lower input increases exposure to interest. Thus, schedule crashing becomes more feasible the smaller the equity input.

The early and late strategy cash flows (given in FIG. 4-4) breakeven curves are now examined. From FIG. 4-10 it can be established that, for projects having normal project financing structures (small equity input, see f=0% FIG. 4-10) an early start date schedule provides a greater allowable change in the capital expenditure when crashing. However,

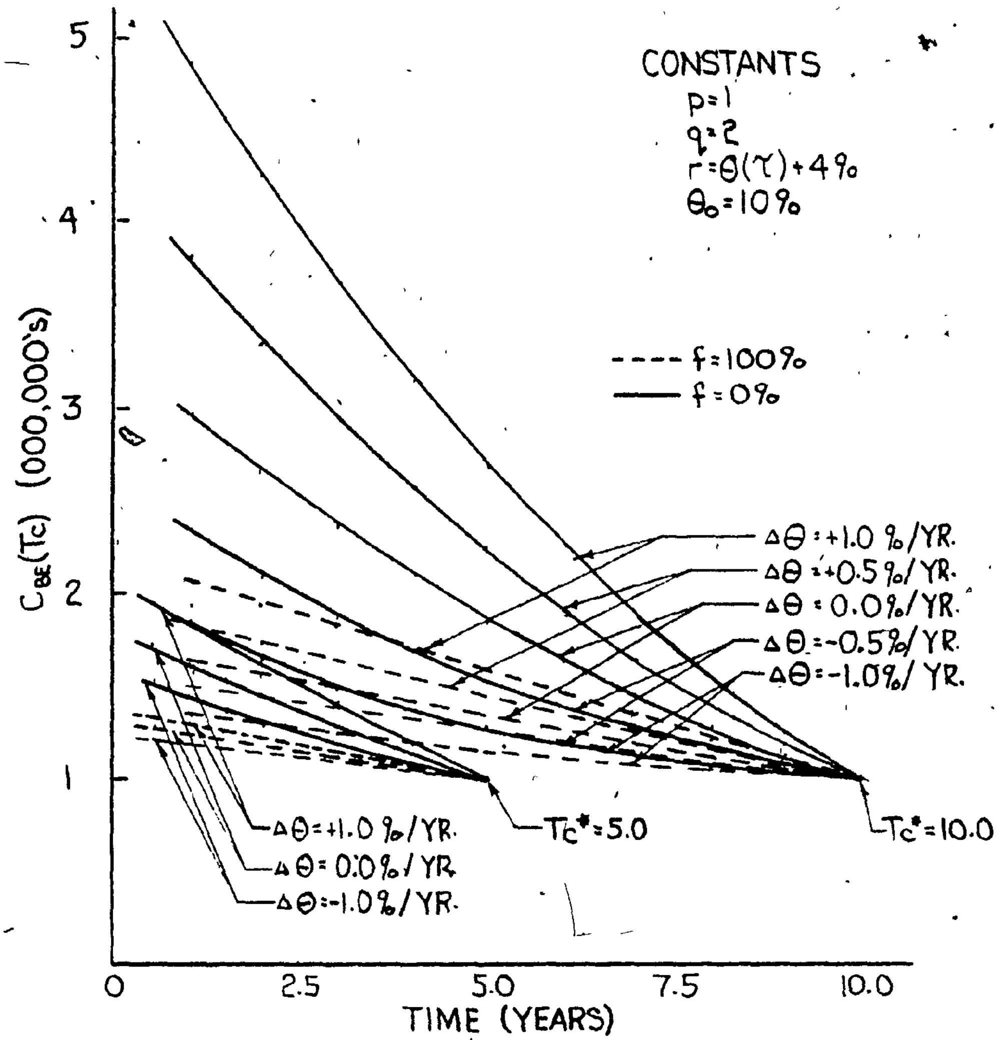


FIG. 4-9
TOTAL COST BREAKEVEN CURVES
DURATION (Tc*) AND RATE OF
INFLATION CHANGE VARIABLE

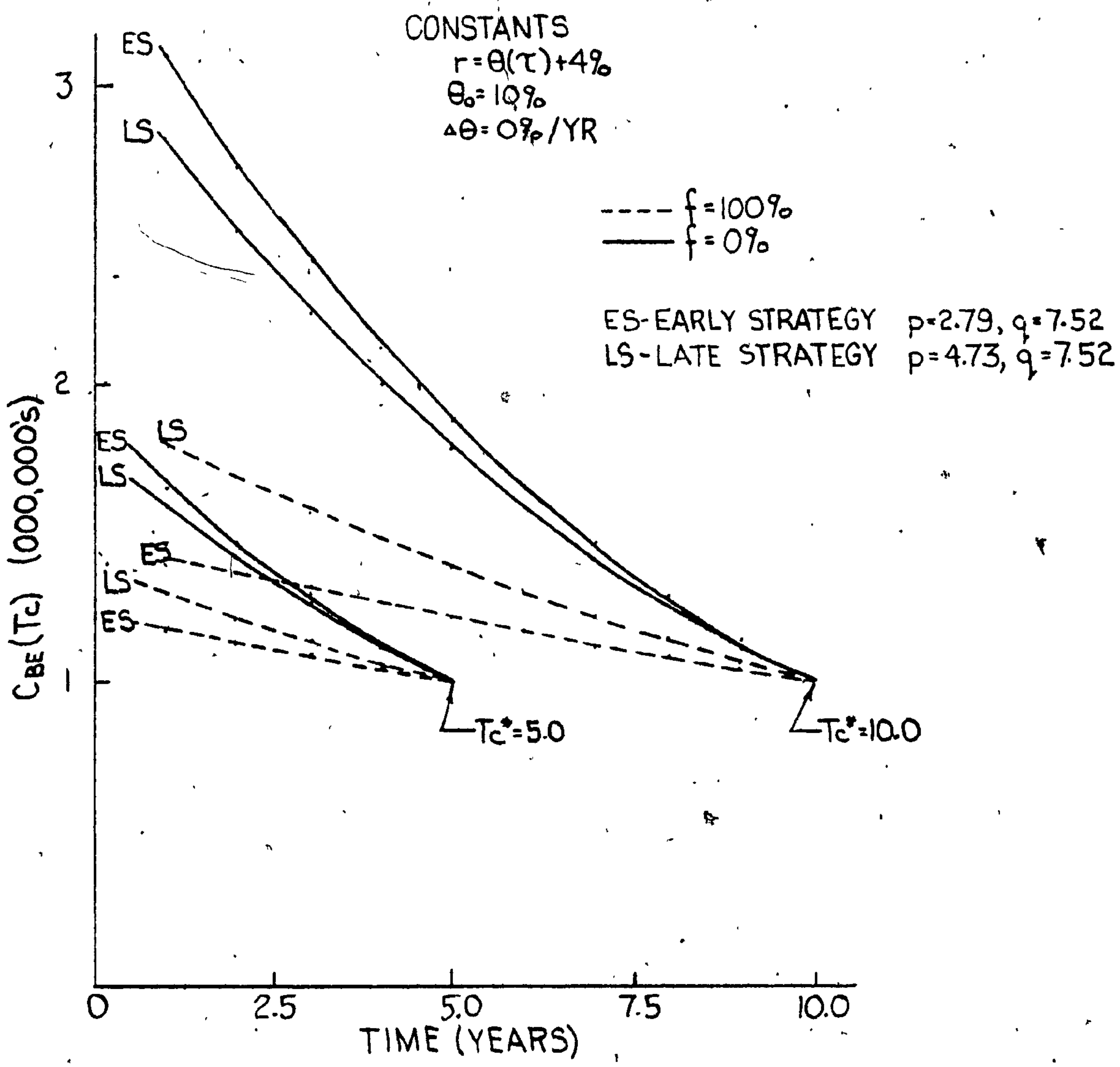


FIG. 4-10
TOTAL COST BREAKEVEN CURVES
EARLY vs. LATE STRATEGY, EQUITY
AND DURATION (T_c^*) VARIABLE

when the equity percentage (see f=100% FIG. 4-10) is high the late start breakeven curve can be steeper than the early start curve. Further, it appears that the slope of the breakeven curve is not that sensitive to cash flow profile shape, particularly for values of Tc close to Tc*. (Tc close to Tc* is expected to be the obtainable range of the breakeven curve).

Sensitivity of breakeven curve slope is further examined using the same early and late strategies. Allowable capital expenditure is recorded for a 20% reduction in construction duration from Tc* as follows;

$f=10\%$

$\theta o=10\%$

$\Delta\theta=0.5\%$ per year

$r=\theta(\tau)+4\%$

TABLE 4.2

EARLY vs. LATE STRATEGY BREAKEVEN VALUES FOR 20% REDUCTION IN Tc*

Tc* YEARS	BREAKEVEN CAPITAL EXPENDITURE C_{BE}(Tc) EARLY STRATEGY	LATE STRATEGY	PERCENT DIFFERENCE
2	$ 1,051,712	$ 1,048,644	0.3
4	$ 1,114,811	$ 1,107,911	0.6
6	$ 1,191,086	$ 1,178,935	1.0
8	$ 1,282,745	$ 1,264,160	1.5
10	$ 1,392,399	$ 1,365,836	1.9
12	$ 1,523,280	$ 1,486,924	2.4
14	$ 1,679,358	$ 1,630,872	3.0
16	$ 1,865,537	$ 1,802,576	3.5

where

$$\text{PERCENT DIFFERENCE} = \frac{\text{EARLY STRATEGY } C_{BE}(Tc) - \text{LATE STRATEGY } C_{BE}(Tc)}{\text{LATE STRATEGY } C_{BE}(Tc)} \cdot 100$$

Thus it may be concluded that the breakeven curve is relatively insensitive to cash flow shape when crashing duration by up to 20% (the assumption made here is that crashing beyond a 20% reduction would be difficult to obtain, this is a topic of actual time/cost tradeoff studies which have not been investigated in this work).

With insensitivity of breakeven curve slope established in the area of utmost concern, it is interesting to consider the use of the "impulse" flow concept of the previous section. Using equation (4.7), a million dollar capital project over 10 years, a base inflation rate of 10% increasing at 0.5% a year, a equity input of 10% and a fixed real interest rate of 4% the total project cost is;

$$TC(Tc^*) = TC(10) = \$4,012,308$$

where $Tc^* = 10$, $t_I = 5$ and $C(Tc^*) = \$1,000,000$. If the construction duration is to be reduced by 20%, to 8 years, the total cost as given by equation (4.7) is;

$$TC(Tc) = TC(8) = 2.9136\ C_{BE}(Tc)$$

so that the breakeven value estimate is;

$C_{BE}(Tc)=4,012,308/2.9136$

$=\$1,377,078.$

This breakeven value produces a 0.1 percent difference when compared to the average of the breakeven values given for the previously tabulated late and early strategies of TABLE 4.2 for Tc*=10 years (average breakeven value from table is $1,379,118). Thus, the "impulse" expenditure concept can be used quite effectively (with $t_I=Tc/2$) to calculate project breakeven values under North American economic conditions.

4-4 NET PRESENT VALUE ANALYSIS

The net present value method of evaluating a project is considered the most straight forward technique employing the concept of time value of money. NPV is an extensively used method of project performance as it considers all cash flows occurring during the life of a project.

In Appendix A a listing of the program used for the determination of project NPV is presented. The program uses equation (3.43) in conjunction with a number of simplifying assumptions so as to minimize model complexity while maintaining a substantial degree of reality. Over the construction phase ($0\leq t\leq Tc$) the assumptions of linear escalation and interest rate correlated to inflation, as presented in equation (4.3) and equation (4.4) respectively, are again used. The interest rate on outstanding debt during the operating life ($Tc\leq t\leq Tp$) is assumed constant given that financing will be in terms of long term debt. Both the project revenues and expenditures functions are assumed to be uniform in profile in terms of constant dollars. Validity of this assumption is of course debatable but felt useful for preliminary development. Other functions can of course be specified but the program is equipped to handle the uniform assumption only. Both the project revenues and expenditures functions are specified by the magnitude of the constant dollar uniform profiles which are then subjected to corresponding linear escalation functions. Revenues and expenditures inflations are defined by a base escalation rate at project start, θ_{R_O} and θ_{E_O}, and a rate of inflation change, $\Delta\theta_R$ and $\Delta\theta_E$, over the project life ($0 \leq t \leq Tp$). Minimum Attractive Rate of Return, combined Federal/Provincial Tax Rate and Project Capital Cost Rate are assumed constant over the project life in this program.

Sensitivity of the NPV performance measure, using the program of Appendix A, is presented for an example project which is roughly construed on actual data for a mining project. Project capital cost is estimated at 135.1 million dollars over a 3 year construction period. Costs during construction are predicted to be subject to a constant yearly inflation rate of 10% ($\Delta\theta$=0). Project financing requirements dictate a 15% equity input with a 12% interest rate during construction and a 9% nominal interest rate on outstanding debt during the project operating life. The operating life of the project, exclusive of the construction phase, is 15 years. Average annual revenues are \$53,650,000 in terms of constant dollars and are expected to escalate at a constant yearly rate of 8% ($\Delta\theta_R=0$). Average project expenses during the operating life are \$15,115,000 per annum and are also expected to escalate at a constant rate of 8% per year ($\Delta\theta_E=0$). Project income tax rate is 40% with a capital allowance rate of 10%. Constant dollar cash flow during construction is assumed uniform so that the beta parameters are p=1 and q=2. Finally the project MARR is set equal to 15%.

The results of a number of NPV sensitivity runs using the preceeding data as the base case and allowing various parameters to vary by plus and minus 10% produced the following results of TABLE 4.3 which are illustrated as sensitivity curves in FIG. 4-11.

TABLE 4.3

RESULTS OF NPV SENSITIVITY RUNS
(NPV CALCULATED IN TERMS OF DOLLARS AT PROJECT START)

SENSITIVITY ANALYSIS PARAMETER	NPV (000's) (CONSTANT \$)
BASE CASE	\$ 113,734
10% INCREASE IN CONSTANT \$ CAPITAL COST	\$ 107,703
10% DECREASE IN CONSTANT \$ CAPITAL COST	\$ 119,810
10% INCREASE IN ANNUAL EXPENSES (CONSTANT \$)	\$ 106,914
10% DECREASE IN ANNUAL EXPENSES (CONSTANT \$)	\$ 120,559
10% INCREASE IN ANNUAL REVENUES (CONSTANT \$)	\$ 137,965
10% DECREASE IN ANNUAL REVENUES (CONSTANT \$)	\$ 89,503
10% INCREASE IN CONSTRUCTION DURATION	\$ 110,705
10% DECREASE IN CONSTRUCTION DURATION	\$ 116,835
10% INCREASE IN PROJECT OPERATING LIFE	\$ 125,071
10% DECREASE IN PROJECT OPERATING LIFE	\$ 101,047

10% INCREASE IN OPERATING LIFE INTEREST RATE	$	110,779
10% DECREASE IN OPERATING LIFE INTEREST RATE	$	116,542
10% INCREASE IN PROJECT TAX RATE	$	105,363
10% DECREASE IN PROJECT TAX RATE	$	122,105
10% INCREASE IN CAPITAL COST ALLOWANCE RATE	$	115,115
10% DECREASE IN CAPITAL COST ALLOWANCE RATE	$	112,274
10% INCREASE IN MARR	$	97,205
10% DECREASE IN MARR	$	133,358

The program allows the examination of project performance as a function of changes in decision variables and uncontrollable parameters. Results of the example project indicate that project go ahead is not sensitive to the range of change considered in the parameters tested. The internal rate of return for the project was found to be 50.2%.

General trends in NPV analysis are straight forward. Lower capital cost will result in a greater internal rate of return. For the assumed project financing conditions a smaller equity input is more desirable because of the spread between total return and the borrowing rate (positive leverage is possible on this example project). Lower interest rates and rates of construction cost inflation increase IRR.

Using the early and late strategy curves of FIG. 4-4 gives respective NPV values of $112,938,000 and $114,542,000 which represent only a 0.7% difference from the NPV value obtained for the base case. As the cash flows of FIG. 4-4 represent a fair magnitude of change it may be concluded that NPV calculation is not that sensitive to cash flow shape.

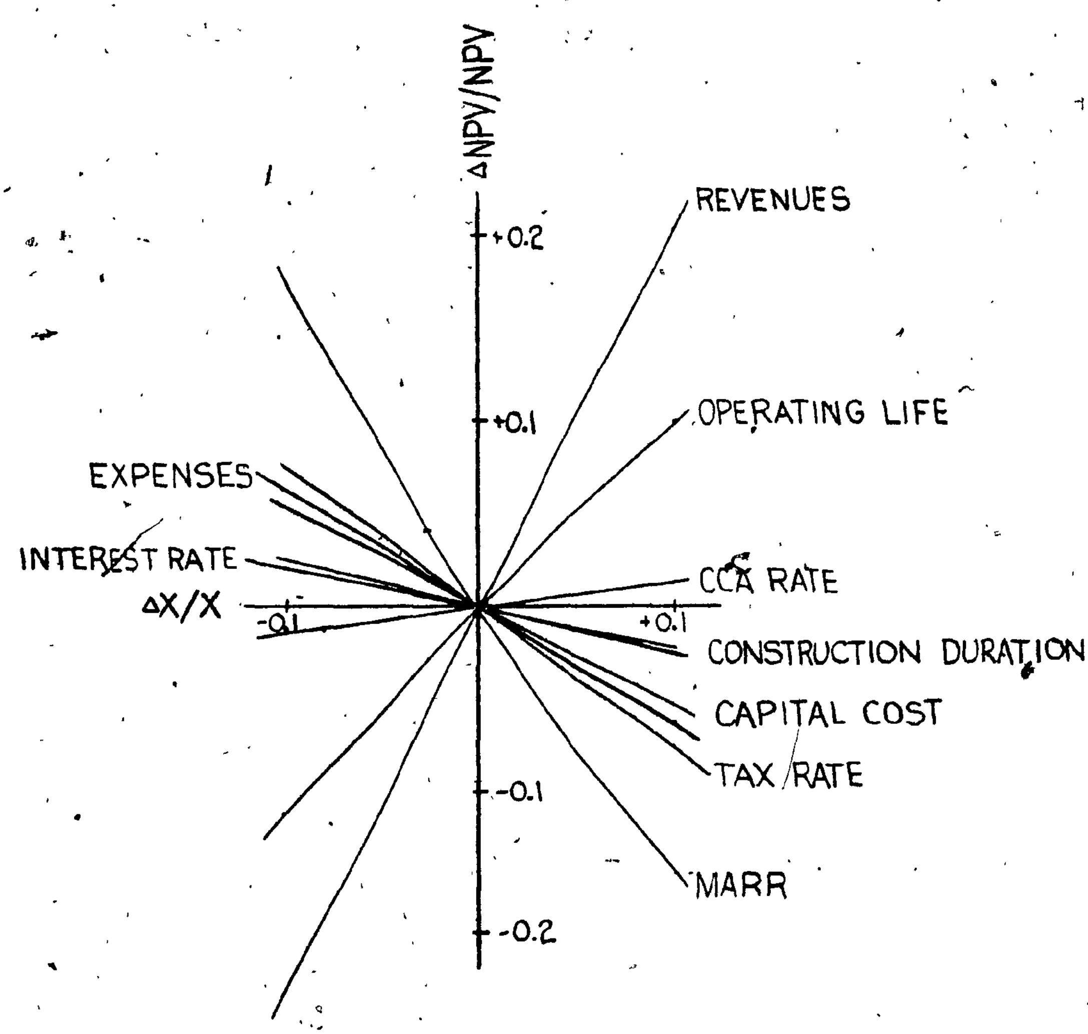


FIG. 4-11
NPV SENSITIVITY CURVES
FROM TABLE 4.3

Thus, the option exists of substantially simplfying NPV calculations through the use of uniform construction cost cash flow.

This section has shown, by example, the use of equation (3.42) for NPV using a number of listed assumptions. These assumptions used can of course be modified to allow more realistic modeling if so desired.

4-5 BREAKEVEN CURVE ANALYSIS: NET PRESENT VALUE

For net present value the breakeven criteria is to determine what value of C(Tc) can be absorbed under the restriction that project NPV must remain constant. Assumptions used for breakeven analysis are as outlined in the previous section for the NPV program except that all escalation functions are restricted to constant values ($\Delta\theta=\Delta\theta_R=\Delta\theta_E=0$).

The mining project example of the previous section is used here for comparison of the NPV and total cost breakeven analysis project performance measures. Examination is confined to project variables of the operating life of the project as the effect of the construction phase was examined in detail in the section on total cost breakeven analysis. NPV and total cost breakeven curves respond in a similar manner to changes in project variables of the project construction phase.

FIG. 4-12 shows that increasing the project operating life duration will increase the slope of the breakeven curve.

This is true when increasing duration increases accumulated revenues as when the revenues and expenditures functions are uniform in terms of constant dollars in this model. (Increasing duration also reduces the rate of loan repayment). However, it must be noted that the revenue function will most likely not be uniform in nature tending instead to taper downwards towards the end of operating life (especially in the case of a mining project). Extension of operating beyond normal life may cause revenues to decline while expenditures may increase which if severe enough may cause the slope of the breakeven curve to decline.

The effect of interest rate charged during the project operating life on outstanding debt is shown in FIG. 4-13. Decreasing the loan interest rate increases the breakeven curve slope. A lower interest rate of course signifies a lower rate of loan repayment which increases yearly net profits allowing for a greater increase in capital expenditure when construction is crashed. It should be noted once again that the interest rate being charged during the operating life has been assumed uncorrelated to the interest rate charged during construction.

In FIG. 4-14 and FIG. 4-15 the effects of increasing and decreasing uniform revenues and expenditures are examined. Increasing revenues increases net profits over operating life duration which in turn allows an increase in capital expenditure spending during construction while maintaining a constant NPV. Similarly, a decrease in expenditures increases net

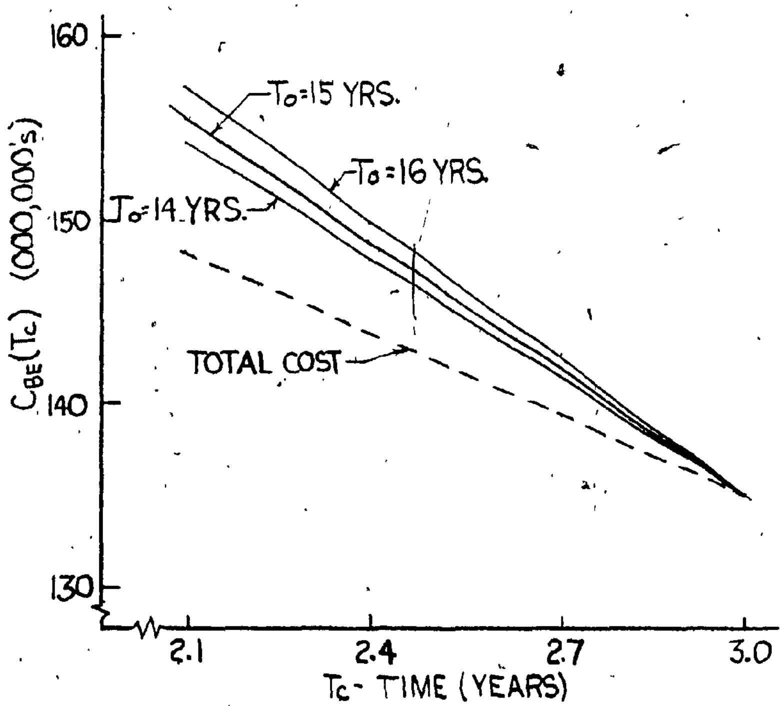


FIG. 4-12
NPV BREAKEVEN CURVES
OPERATING LIFE (T_o) VARIABLE

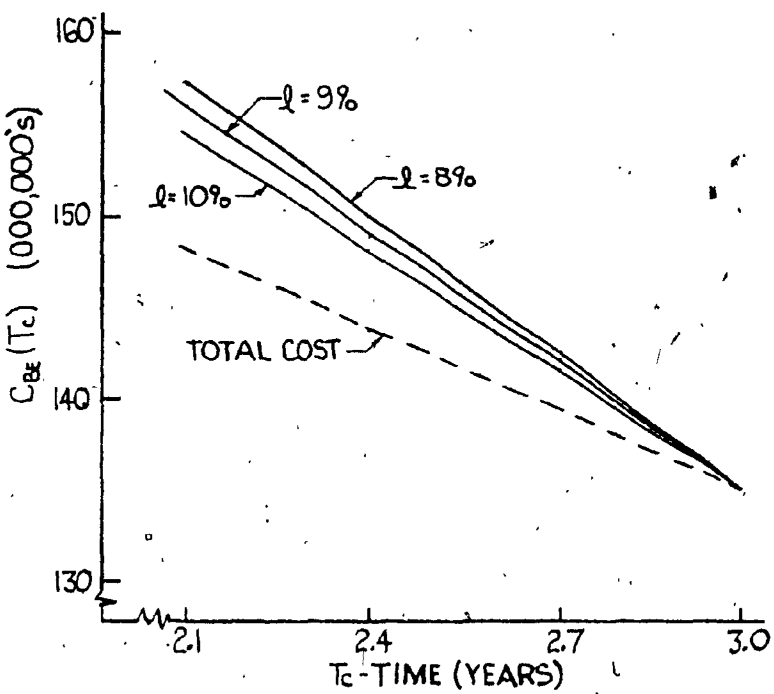


FIG. 4-13
NPV BREAKEVEN CURVES
OPERATING INTEREST RATE (ℓ) VARIABLE

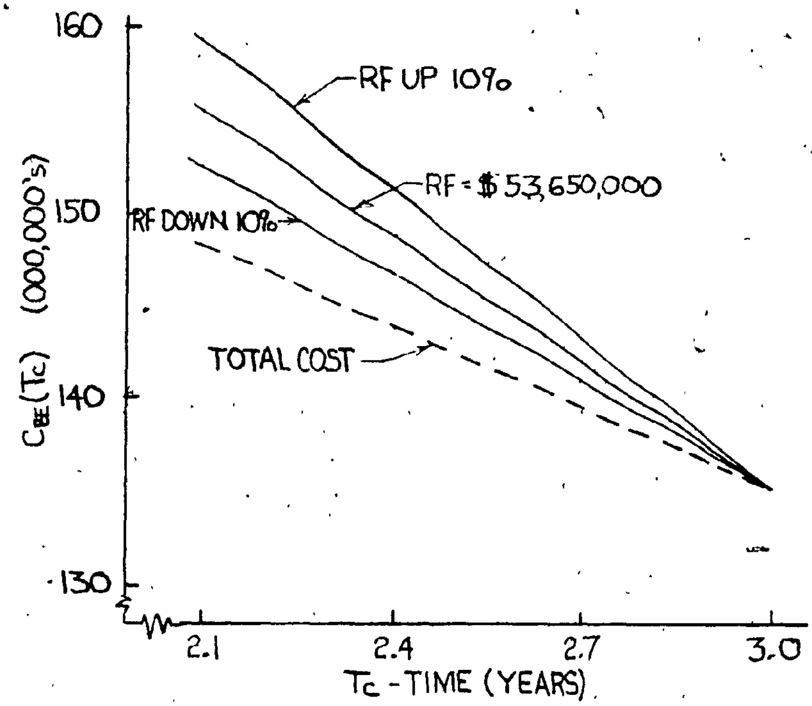


FIG. 4-14
NPV BREAKEVEN CURVES
ANNUAL REVENUES (RF) VARIABLE

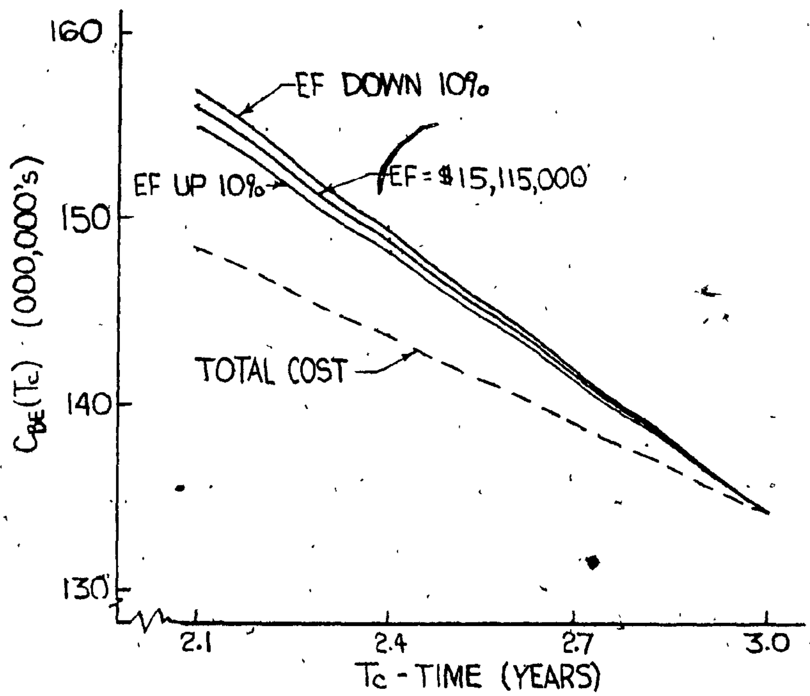


FIG. 4-15.
NPV BREAKEVEN CURVES
ANNUAL EXPENDITURES (EF) VARIABLE

profits during project operation and allows the slope of the breakeven curve to increase. It is important to realize (4) that the size of error in estimating revenues can far exceed that of other variables. This possible error in conjunction with the high sensitivity of $C_{BE}(Tc)$ based on NPV makes selection of the best crashing strategy difficult.

Another parameter investigated is the minimum attractive rate of return, FIG. 4-16. Results of this figure tend to suggest that a higher MARR will increase the slope of the breakeven curve. However, FIG. 4-17 examines breakeven values versus MARR for a reduction in construction duration from 3.0 to 2.7 years. Thus breakeven slope may increase or decrease depending on the MARR making any general trends difficult to observe.

Tax rates and capital cost rates are determined by government legislation and would be expected to remain constant. However it is interesting to observe the shift in breakeven curves if tax rate and capital cost rate change. Changes are possible due to changes in government policy or special considerations given to large projects. Lower taxes increase slope whereas lower capital cost rates decrease breakeven curve slope as illustrated in FIG. 4-18 and FIG. 4-19.

The results of total cost breakeven analysis for the mining project example are indicated by a dashed line in FIG. 4-12 through FIG. 4-19. For this particular project, under the conditions assumed, when crashing is undertaken, the NPV breakeven criteria would appear to allow a greater increase

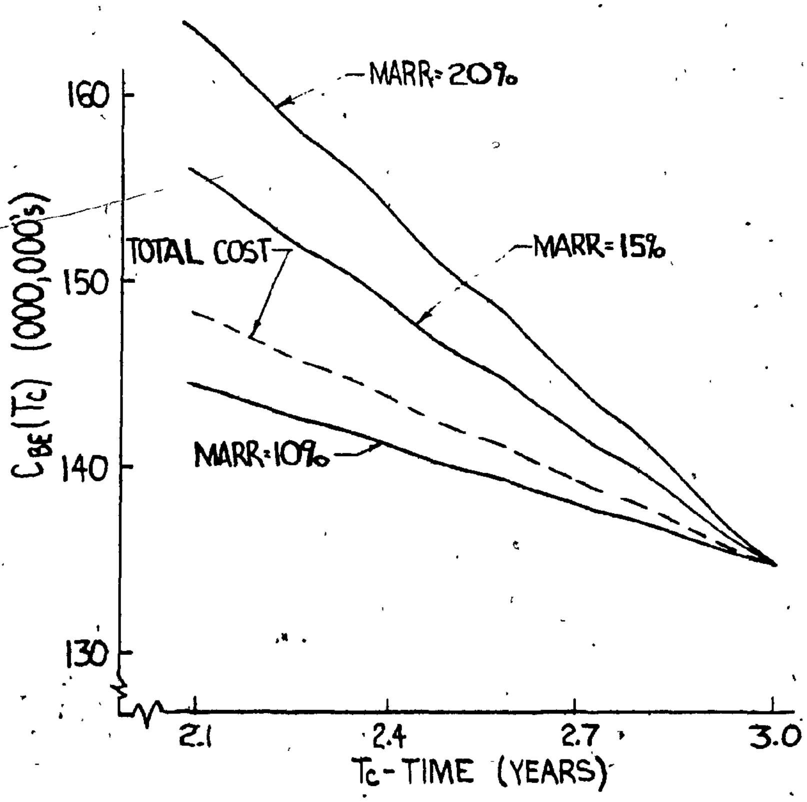


FIG. 4-16
NPV BREAKEVEN CURVES
MARR VARIABLE

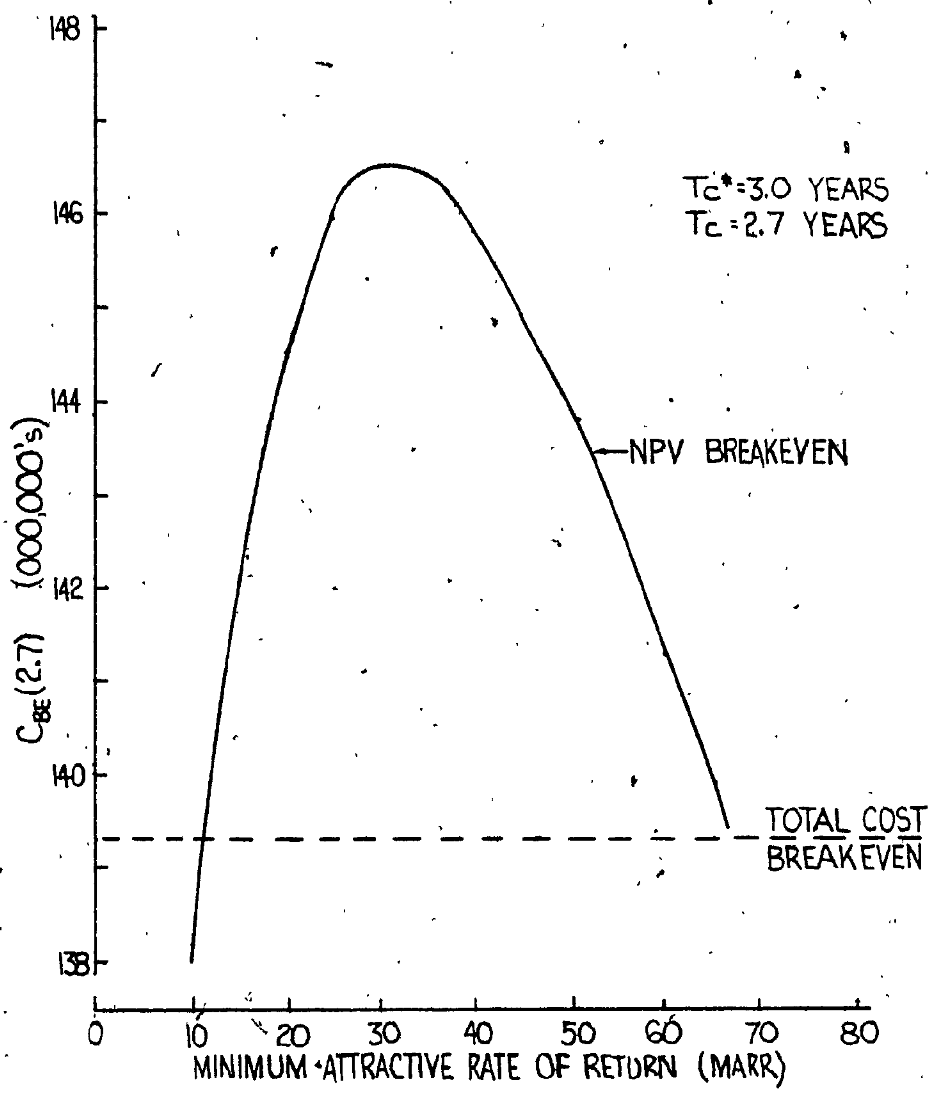


FIG. 4-17
BREAKEVEN COST vs. MARR
CONSTRUCTION DURATION REDUCED
TO 2.7 YEARS FROM 3.0 YEARS

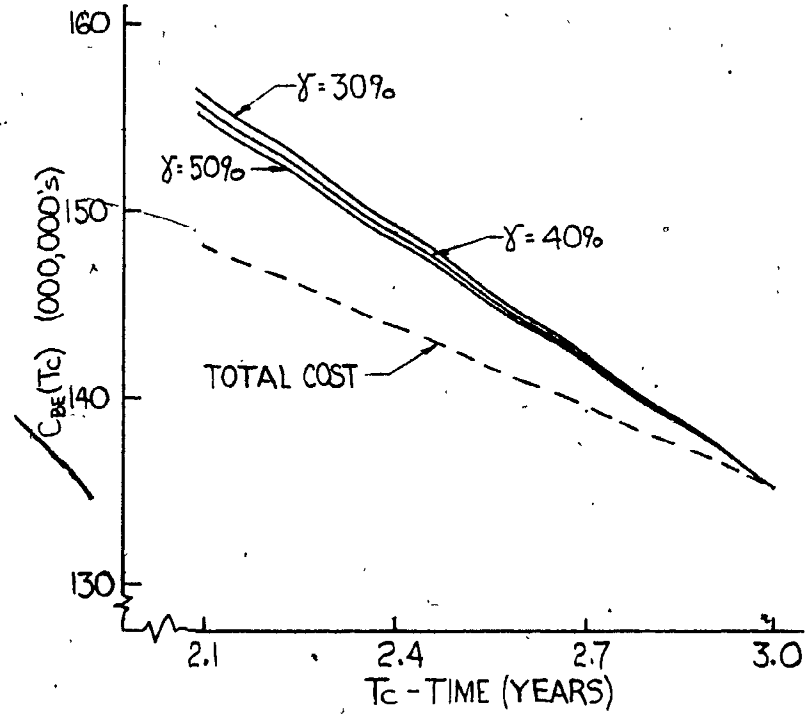


FIG. 4-18
NPV BREAKEVEN CURVES
TAX RATE (γ) VARIABLE

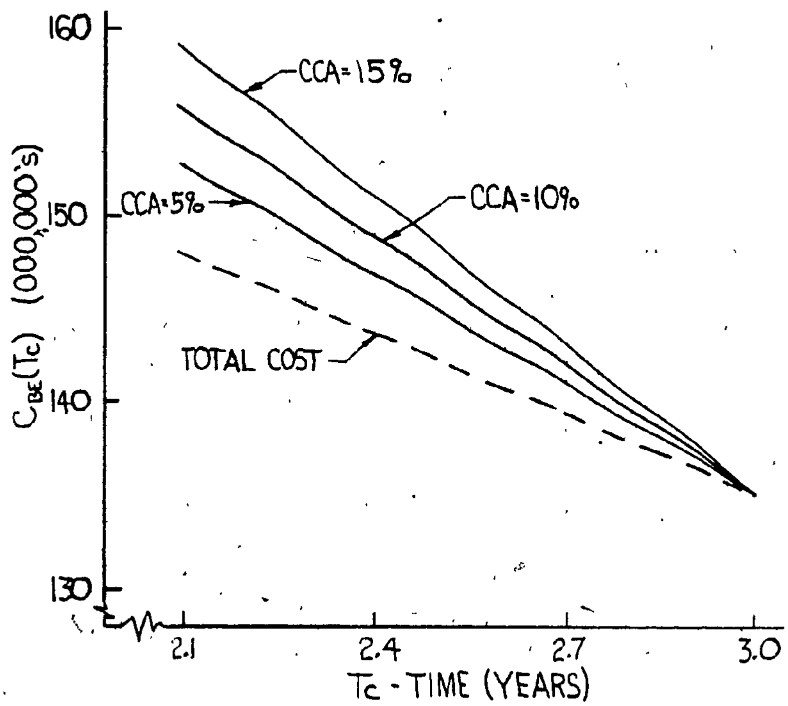


FIG. 4-19
NPV BREAKEVEN CURVES
CAPITAL COST ALLOWANCE (CCA) VARIABLE

in capital cost than the total cost breakeven criteria. (FIG. 4-16 for MARR=10% shows an exception to this general observation for the example project. A search for other exceptions was not undertaken at this time).

This section has shown practical use of equation (3.49) under stringent but still realistic restrictions. More realistic analysis can of course be performed by modifying the assumptions used in this section. The results of future work will verify whether the trends suggested by the example mining project are general or specific in nature.

4-6 SUMMARY

The theoretical concepts presented in Chapter 3 have been investigated by way of example projects in this Chapter. Results of analysis produced some very interesting properties, particularly with respect to construction cash flow profile shape. Insensitivity of investigated project level performance measures to cash flow shape allows simplification of the analysis techniques required. In particular, use of an "impulse" expenditure when calculating project total cost and its components appears to give sufficiently accurate results, at least for the examples examined.

Total cost and NPV analysis allowed evaluation of the impacts of variation in construction duration, inflation and interest rate scenarios, rate of inflation increase, equity input percentage, late and early start scheduling strategies, operation revneues and expenditures, operation phase duration, minimum attractive rate of return, tax rate and capital cost rate.

Breakeven analysis indicated the feasibility of schedule crashing without the incurrence of increases in total project cost or project net present value. Sensitivity of the break-even curve slope to changes in each of the project level variables was examined and some general trends observed were noted.

4-7 APPENDIX: BEST FIT BETA PARAMETERS

In this section presentation of method of determining best fit beta distribution parameters is given.

The mean of the beta distribution is;

$$\mu = p/q$$

where p and q are the beta parameters. Variance is given by;

$$\sigma^2 = p(q-p)/(q(q+1)q).$$

For a given cash flow the mean and variance can be easily determined using statistical methods. With the mean and variance known, the values of p and q may be determined by noting that variance may be expressed as;

$$\sigma^2 = \mu(1-\mu)/(q+1)$$

which upon rearrangement becomes;

$$q = (\mu(1-\mu)/\sigma^2) - 1$$

which leads to the equation giving the parameter p;

$$p = (\mu^2(1-\mu)/\sigma^2) - \mu.$$

CHAPTER 5

MICRO MODEL: ACTIVITY LEVEL OF ANALYSIS

So far attention has been focused on the project level of analysis. Project level cash flow profiles were allowed to vary providing a gain in understanding of how changes in the project level decision variables affect the project performance measures. This chapter considers how the previously assumed changes in project level cash flows can in fact be obtained.

The project level is an aggregate of individual activities and it is to these activities attention is turned. Obviously changes implemented to the activities (the activity or action level) will affect both the individual activity cash flows and the project cash flow when the altered activity is reintroduced at the project level.

The hierarchical nature of construction management analysis makes it difficult to produce modeling techniques which meet the criteria of all management levels. At the upper end of the hierarchical scale, management is concerned only with broad project concepts. Lower levels are concerned with the actual accomplishment of individual work units which when aggregated produce the project. It is to this lower level, which includes technologies, methods and resources employed in the field, that attention must be focused in order to determine how activity level decision variables affect activity and project cash flows.

In this chapter a generic model of an activity called a Micro Model will be constructed. Activity modeling necessitates analysis of the operations comprising the activity installation phase. The Micro Model allows evaluation of various strategies that may be employed to cause change in cash flow and duration through the manipulation of activity level decisions.

5-1 MODELING CONCEPT

Modeling viewpoints in construction management are dependent on the hierarchial level at which a decision must be made. Upper management is concerned with broad project statements allowing comparison between actual and estimated progress. At lower levels of management, interest is in gross determination of resource availability, suitability, feasibility and efficiency.

A model becomes more attractive when it can be employed over more than one specific stage of the project life-cycle and when it is capable of handling a number of functions. The main focus of the Micro Model is the conceptual or pre-planning stages of the project life-cycle where the primary concern is on feasibility and the control of time and cost rather than the actual performance of the construction itself. However, the concepts employed in the Micro Model formulation allow investigation of the actual resources employed in construction. This allows the model to be used throughout the life-cycle and at different levels of management as a tool to aid in the planning, scheduling and monitoring of a project.

Existing conceptual construction modeling techniques available for construction management include bar charts, line-of-balance models, multiple activity and crew balance charts, critical path methods (CPM), queuing models and simulation (45). The Micro Model, described herein, is deterministic in nature and uses homogeneous operations linked together in a network; it is integrally linked to the critical path modeling technique.

CPM involves the representation of a project plan by a network depicting the sequence and interrelation of all component parts of the project. Network analysis and manipulation allows determination of the best program of construction.

Determination of the optimum time required for each work process and the most economical use of available resources are the basis of a fully developed CPM network. The Micro Model takes into account the individual resources required for a particular activity in accordance with the anticipated conditions of the project.

Using the Micro Model an activity can be established so that resource useage is optimum. The resulting activity time and cost are then available for conventional CPM analysis techniques (32) (33).

During project execution the Micro Model can be used to re-evaluate critical activities; particularly when project acceleration is desired. Allowances can be made for uncertainities in the original planning as well as for reconsideration of future uncertainties.

The Micro Model is structured to take into account the actual interrelationships and environment of construction so as to allow for the dynamic interaction of activity resource requirements.

5-2 ACTIVITY DESCRIPTION

In networking techniques such as CPM an activity is defined as a unique unit of the overall project that can be described within prescribed limits of time. For purposes of this study an activity requires many resources, substantial expense and a significant amount of time. An activity is an element normally defined for use in time and cost planning and control of overall project performance.

Selection of equipment requirements and construction methods of activities must be considered early in the pre-construction phases of a project. To properly describe an activity requires establishing as much information as possible about the following:

1) Manpower - amount of labor involved, labor productivity, useage, availability, skill level, etc.

2) Machines - types of construction equipment required, when needed, availability, quantity required etc.

3) Materials - quantity and types of materials, including permanent equipment, needed to perform the work, availability, delivery time etc.

4) Money - amount and timings of money required and limitations on availability.

5) Methods - construction technologies that can be used.

6) Management - processes used for planning, control, procurement, layout; level of management resources.

7) Time - constraints placed on start, finish and other milestone dates.

These seven factors are the activity level decision variables. Changes implemented in any or all of these will reflect on the activity and thus the overall project. It must be constantly borne in mind that many interrelationships exist between the decision variables. Making a selection for one variable will most likely constrain the number of choices available for the remaining variables.

The focus in this section is being maintained at the basic project and top management planning levels. An activity is related to the production of a unique physical segment of the total project. The aggregation of various field actions and technological processes produce the activity.

Extensive use of activities is encountered in time scheduling methods (CPM) employed by upper level management where concern remains with broad project concepts rather than actual performance of the work. At this upper level of analysis the degree of project work breakdown is still very limited.

The activity life-cycle may be considered as consisting of three phases, FIG. 5-1. The first phase is designated as the design phase. Here concern is with the preparation and finalization of all plans and specifications required to perform the activity. Procurement is the term applied to describe the second activity life-cycle phase. The objective of this phase is obtaining all materials necessary to produce the desired activity facility. Procurement packages are assembled, tendered and awarded. Materials must be available on site when needed during construction. The final phase is installation. Installation is the actual physical construction of the activity facility in accordance with plans, specifications and contract documents.

In FIG. 5-1, the time relationship between the three activity phases are shown. The total activity duration is the summation of times required for each of the three phases less any allowable overlap between phases.

For purposes of the model developed herein the time required for design and procurement phase durations and design and procurement-installation overlaps are assumed to be within estimating capabilities. The time required for engineering and design work can be reasonably estimated using historical data (36). Procurement duration can be established from signed contracts, manufacturer's estimates and past project experience.

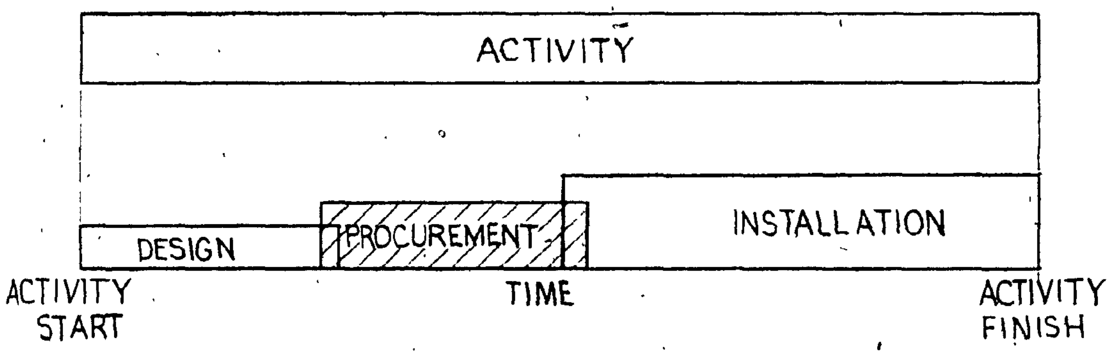


FIG. 5-1
ACTIVITY LIFE-CYCLE PHASES

Costs associated with the design of the activity can be determined once the approximate activity cost is established (36). Design phase cost is not included in the model although design phase duration is.

The only cost of concern during the procurement phase will be assumed to be prepayments required on significant procurement packages. Other procurement costs are neglected or may be considered incorporated in installation phase material costs. It is procurement time or lead time which are of significance to the model rather than the costs of procurement.

To complete the description of the activity in a generic manner requires determination of installation phase duration and cost. Activity installation is the life-cycle phase most affected by the activity level decision variables. Although the preceding phases are of importance it is on the installation phase that emphasis will be placed for model development. More detailed consideration of the first two phases is considered a topic beyond the scope of this work.

At the activity stage of analysis work breakdown is of limited degree. The activity is being presented as a complex entity comprised of a multitude of construction sequences. This level of breakdown makes it a difficult if not impossible task to assign meaningful knowledge about the activity level decision variables. This inability dictates that the activity installation phase be subdivided into homogeneous units to which meaningful values of activity level decisions can be

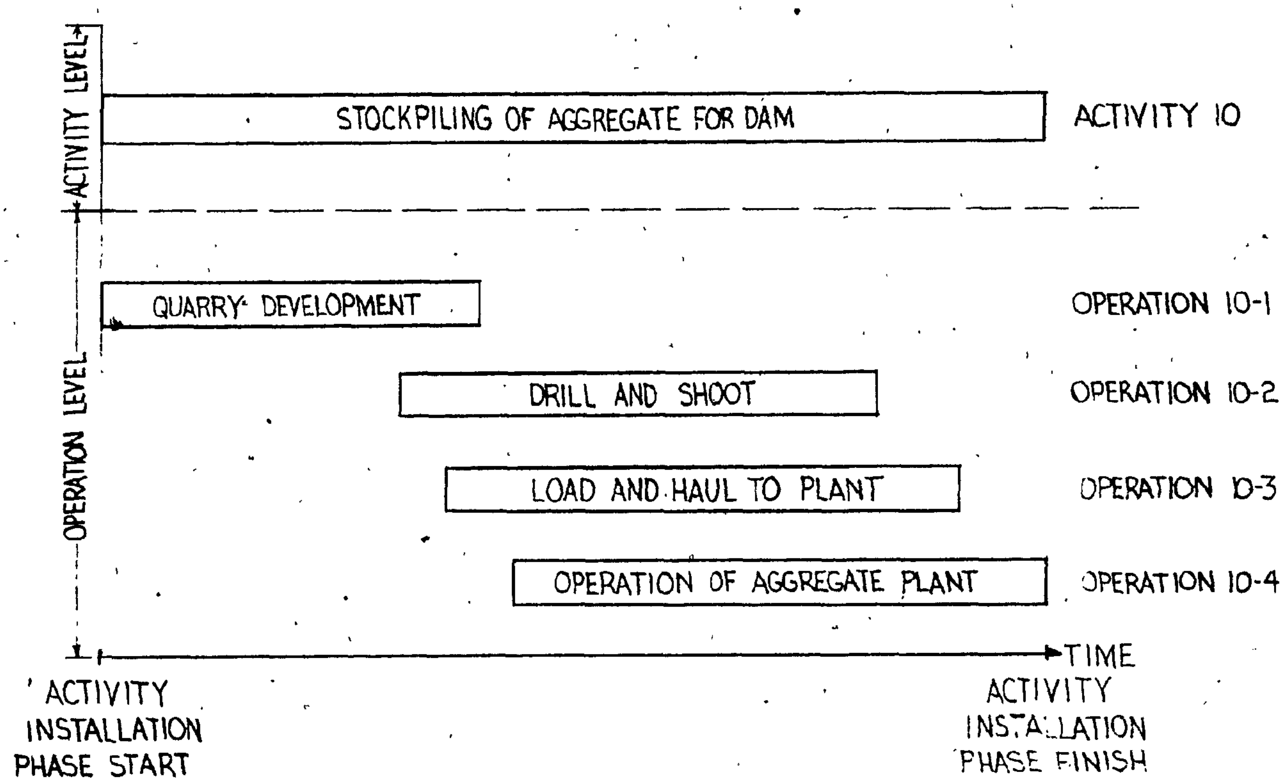


FIG. 5-2
ACTIVITY INSTALLATION PHASE AND OPERATIONS LINK

applied. These homogeneous units of the activity installation phase can thus be represented by a network of operations as illustrated in FIG. 5-2.

Before proceeding to the description of operations, one further cost category should be considered for the activity. This cost is the cost of mobilization. It is characteristic of labor intensive activities to find that costs for mobilization and demobilization of work crews are negligible. Contrary to this are capital intensive activities where the costs incurred with the use of heavy construction equipment can be substantial. This cost is introduced to account for equipment, specific plants and other costs, and it is allocated to the entire activity rather than being prorated to individual operations.

5-3 OPERATION DESCRIPTION

Operations are basic to the accomplishment of a project. At this level of analysis concern is with the actual technology employed and the details of how the construction is to be performed. The operation is closely related to the means of actually achieving the final product being either repetitive or unique in nature.

The activity installation phase must be broken down into measurable homogeneous subdivisions (operations) to which can be applied, conveniently, measures of the activity level decision variables. Individual operations have associated factors that can be identified such as productivity, equipment useage, labor requirements, etc. while the activity installation (the aggregate of operations) is too complex in nature to allow easy identification of these factors.

Again, for the operation, concern is with the technology and details of how the construction is to be accomplished. The operation is closely related to the actual means employed in achieving an end product. Therefore, it is linked only indirectly with a physical segment of the completed activity facility while being directly linked to specific construction methods.

The operation is composed of only the actual construction as all design, engineering, planning and procurement has been performed during the first two activity phases. Operation duration is dependent on activity level decision variables, controllable or not. Following along the lines of networking methods a time duration must be estimated for the operation. Alterations to this estimated duration may be made if resulting activity level decision variables do not meet required constraints. (As an example, if the duration selected is too short, the model may output a manpower peak in excess of manpower availability. This could then be rectified by lengthening the estimated operation duration).

One performance measure, time, has now been accounted for in the operation. The second performance measure is that of operation constant dollar cost. Costs associated with the operation fall under direct and indirect cost categories. The basic principle involved is to charge directly to construction operations all elements of cost that can be handled in that way and to prorate those that cannot be readily broken down. To reiterate, direct costs are the costs of actual field work while indirect costs include such elements as overhead, general expense and general plant.

Cost elements that must be included and that are assignable to the operation may include:

1) labor and insurance,
2) permanent materials,
3) specific plant,
4) equipment rental and
5) supplies and expenses.

The cost headings selected are applicable to both the direct and indirect costs. However, careful consideration is required in the assignment of indirect costs.

Labor and insurance consists of basic wages, fringe benefits, tax, insurance and social benefits. This cost will be a function of the number of men required to be working at any time during the operation.

Permanent materials include purchase price of materials, parts or installed equipment that are built in or become a component part of the completed facility.

Specific plant covers all costs involved in providing at the job site built-in construction plant facilities. This category does not include mobile or movable construction equipment. Specific plant are immovable facilities that must be built in or affixed to the site to serve a function in the performance of the required work (e.g. a concrete batching plant).

The fourth category is that of equipment rental. This category covers costs associated with the use of major mobile or movable equipment. It does not include equipment installed in specific plants and minor equipments that are charged as work supplies. Equipment charges are usually given by a rental rate. The cost of equipment, freight, move-in, erection and dismantling should be assigned to the operation requiring the equipment or, if more practical, to the activity in which the operation occurs.

Final cost category is that of supplies and expenses which covers all expendable items required to perform the field work. These items do not become a part of the completed facility. Included here are services used in the performance of field work and tangible property (fuel, lubricants, repair parts for plant and equipment, electric power, concrete formwork, small tools etc.).

Choice of cost categories for the operation is dependent on the job at hand and the available information. The cost categories chosen are not in any way rigid but as defined provide clear, measurable and understandable divisions of an operation's costs of field work.

Summation of the cash flows associated with each of these five cost categories of the operation will produce the operation constant dollar cash flow.

5-4 CASH FLOW: RELATIONSHIP BETWEEN LEVELS

The previous section described the operation and how its cash flow could be modeled. Activities by definition are composed of operations. It follows then that activity cash flow can be constructed by establishing the cash flow for each operation in the activity and taking the summation of these flows. The resulting activity cash flow is placed back in the project level of analysis. Summation of the activities cash flows gives of course the project cash flow in terms of constant dollars. This allows a return to the project level of analysis where the constant dollar cash flow can be escalated to account for inflation.

The relationship may be best expressed through example. Suppose an analysis of a project is complete and the derived project level cash flow is as appears in FIG. 5-3A. A condition arises that requires the shortening of the overall project duration while retaining the established project level network logic. The project level network, FIG. 5-3B, is scrutinized for activities that have a real possibility of duration shortening. This search would most likely be confined to activities occurring on the critical path of the project network. A so called "critical activity" that appears capable of sustaining a shortened duration is isolated for analysis. This activity has a cash flow profile as illustrated in FIG. 5-3C. The activity level network, FIG. 5-3D, is then examined and a number of "critical" operations are selected for analysis (because of operation interrelationships). Assuming that only one operation will be adjusted in this example the operation's cash flow is as illustrated in FIG. 5-3E. Suppose, as an example, it is

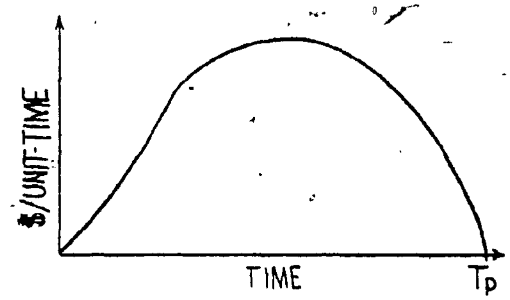


FIG. 5-3A
PROJECT CASH FLOW

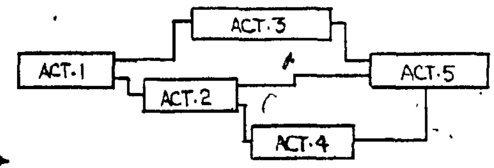


FIG. 5-3B
PROJECT NETWORK

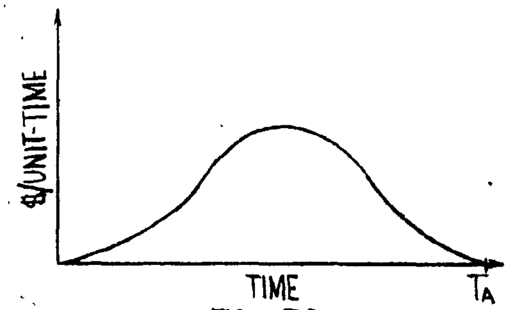


FIG. 5-3C
ACTIVITY CASH FLOW

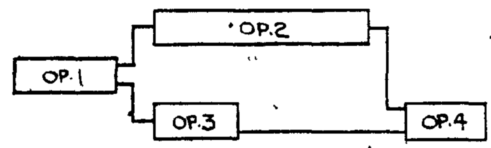


FIG. 5-3D
ACTIVITY NETWORK

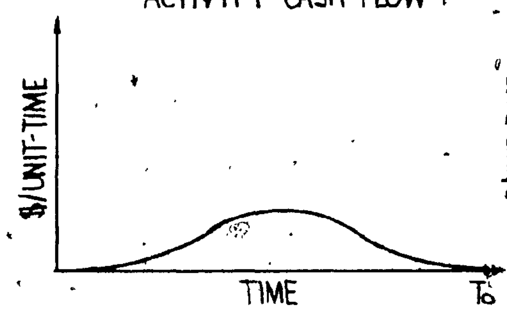


FIG. 5-3E
OPERATION CASH FLOW

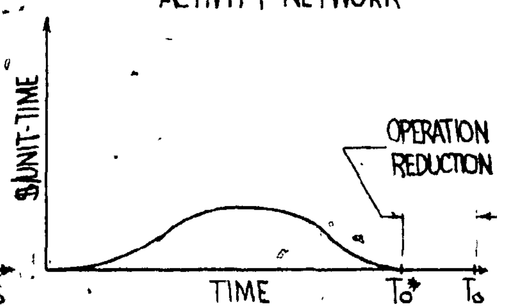


FIG. 5-3F
MODIFIED OPERATION CASH FLOW

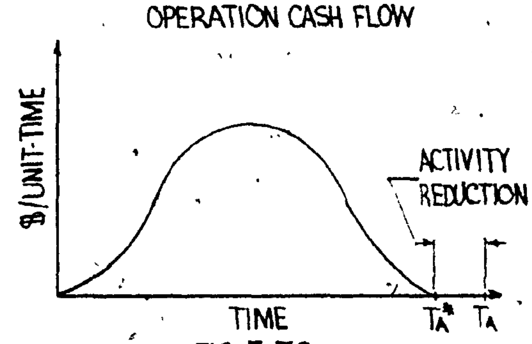


FIG. 5-3G
MODIFIED ACTIVITY CASH FLOW

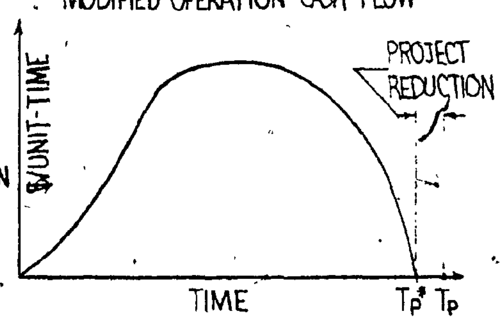


FIG. 5-3H
MODIFIED PROJECT CASH FLOW

FIG. 5-3
CASH FLOW RELATIONSHIP
BY EXAMPLE

found that by slightly altering the construction methods employed in the operation that labor productivity could be improved. Improved productivity in turn reduces the required operation duration without employing more labor resources. In addition to method modification both activity level network logic and the employed levels of resources may be manipulated. Both a modified operation duration and cash flow profile are obtained, FIG. 5-3F. The summation of the modified operation cash flow with the other unmodified operations of the activity produces a modified activity cash flow, FIG. 5-3G. This modified activity cash flow is returned to the project level which in turn modifies the project cash flow, FIG. 5-3H. This modified project cash flow can now be analysed using the Macro Model techniques of Chapters 3 and 4.

5-5 GENERAL OPERATION MODEL

The operation has been defined and is now modeled quantitatively. The performance measures selected were time and constant dollar cost thereby leaving five decision variables (manpower, machines, materials, methods and management). Management and method are exogenous variables to the model. That is, a given management structure approach and method of performing the operation are selected independently, or outside the model. The composition of these two variables will directly impact the input values of the three remaining variables. Reiterating, men, machines and material decision values are dependent on decisions made external to the model as well as being dependent on each other. A complete understanding of possible interrelationships as well as external factors must be observed and accounted for in the input of the three remaining variables to the model. The impact of varying construction methods is a prime focus of the model. Various construction methods for the operation can be considered and compared using the model. However the impact of changing management structure is at present not well understood. Management structure deals with allocation of management resources and quality of decision making, and these issues have a direct impact on productivity through sequencing, site layout, etc. As effects of management structuring become better understood they can be further incorporated in the model.

The operation duration is assumed to be a direct function of the amount of labor, its respective productivity and the required quantity of work (24).

Let Q(To) be the known total quantity of work units to be performed during the operation (work-units). L(t) will be the labor useage at any time t (man-hours/unit-time), and P(t) the labor productivity at any time t (work-units/man-hour). To is the operation duration, $Oo \leq t \leq To$, and Oo the operation start.

The total quantity of work placed is,

$$Q(T_c) = \int_{t=Oo}^{t=To} L(t)\ P(t)dt \qquad Oo \leq t \leq To\ .$$

equation (5.1)

where To is the unknown and must be solved for by iterative techniques unless L(t) and P(t) are simple functions.

A problem arises in obtaining equations for labor useage, L(t), and labor productivity, P(t). The equations selected to satisfy equation (5.1) must be applicable for any To (or a sufficient range of To). Operation L(t) may tend toward a uniform profile for relatively short durations but in general will be nonuniform. Rather than defining these two equations over an unknown time interval the operation model instead requires the installation duration to be a fixed value selected by the user. This requirement too has its limitations but follows logically from network planning techniques where the so called "activity durations" are selected with a degree of both formality and intuition (33). To establish a duration estimate of the operation both an average productivity and size of work crew must be essentially guessed using past experience and judgement. When L(t) and P(t) are constants, the duration, To, can be found easily from equation (5.1).

From equation (5.1) the quantity of work units placed at any time t are,

$$Q(t)=\int_{\tau=0o}^{\tau=t} L(\tau)\ P(\tau)d\tau. \qquad \text{equation (5.2)}$$

Taking the derivative with respect to time t,

$$dQ(t)/dt=q(t)=L(t)\ P(t) \qquad \text{equation (5.3)}$$

where q(t) is the rate of placement of work units at any time t (work-units/unit-time).

The standard method of analysis of equation (5.3) as supported by references 22 and 23 is to solve for the labor useage, L(t). Labor useage is found by applying the "productivity to base unit erection rates developed through estimating methods of the company" which provides an estimate of required manpower which in turn provides the labor useage. Rearranging equation (5.3);

$$L(t)=q(t)/P(t) \qquad 0 \le t \le T_o$$

equation (5.4)

provides the basic relationship upon which the model is based. Equation (5.4) requires that functions for both the rate of placement, q(t), and labor productivity, P(t), be established over the estimated operation duration.

S-curves used in the project level analysis for cost versus time also find widespread use in modeling quantity of work complete versus time (37). It is suggested in reference 23 that given the established operation duration which is set by constraints, past experience and knowledge, that the required placement rates can be established through estimating methods. The Beta function has previously been shown to model well the S-curve and is therefore selected in this work to model the rate of operation work placement, q(t).

Labour productivity analysis almost universally assumes productivity rate to be a constant throughout an operation, activity and project. The standard method is as outlined in references 21 and 23. A "base productivity rate" (constant) is established through analysis of past projects and outside data. Modification factors are then applied to the base rate to account for project specifics. Labor relations, labor availability, skill level, project size vs. availability, schedule, local economic conditions, project complexity and use of overtime are but a few of the project specific considerations for which modification factors may be established. Using this standard approach productivity becomes a constant,

P(t)=constant=(base productivity rate)*(modification factors).

Assumption of productivity being a constant certainly simplifies analysis and may in fact hold true for short time intervals. However it is well known that over time labor productivity does not remain constant (22) (23) (24), due to the dynamics of construction. Variability is due to weather conditions, working conditions, learning curve effects, labor climate etc. Typically productivity rates start off poorly, gradually increasing to a maximum in the middle stages of a job then tapering off towards job completion (23). This productivity profile can be modeled well by a quadratic equation which is capable of degeneration to the special case of constant productivity (straight line).

The difficulty in predicting productivity values is not overlooked but is beyond the scope of this work (21) (23).

While it may appear reasonable to assume a quadratic accounts for learning curve effects as well as end of job rework and schedule deadlines it fails to account for seasonality effects. Seasonality can be an important consideration as outlined in CERL Technical Report P-15 (25). The report however provides no generic conclusions or concepts about seasonality other than that its effects can be significant. In the present model seasonality could perhaps be accounted for by imposing a wave function such as a sine curve over the quadratic function selected. (This option was not pursued). Further, productivity values obtained from past projects will already incorporate seasonality. In estimating effect of seasonality on operation productivity a return to the project level must be incorporated to determine at what time of year the operation will be executed.

Another difficulty encountered is that productivity is required to be estimated before manpower loading is known. Iterative analysis is therefore required to account for peak manpower loads, learning curve effects etc., in estimating productivity.

In order to create the operation model the step of choosing representative equations must be undertaken. The selection of the beta curve and quadratic to model rate of placement and productivity respectively are not rigid constraints on the operation model but are used here for illustrative purposes only. It is felt that the equations selected are reasonable choices based on research to date.

If further research indicates that rate of placement and/or productivity may be represented more accurately by functions other than those selected they may be easily incorporated in the operation model. All that is required is substitution of the new function(s) for the old. This substitution does not alter the basic definition and structure of the operation model.

Returning to equation (5.4), with the rate of placement and productivity functions established, the labor useage profile, L(t), and thus the labor resource profile can be obtained. This labor resource profile (manpower loading) may be used as a check on the operation duration, productivity and rate of placement values initially inputted. If the manpower profile produced is acceptable no modifications to the input are required. However the manpower curve may prove unacceptable because of peak overload or because productivity values selected did not account for the particular labor profile produced. In this case adjustments must be made to the input data (operation duration, productivity, rate of placement) until a suitable labor resource profile is obtained.

The operation model's output are a labor profile and constant dollar cash flow; costs accruing to the owner. The costs associated with the operation are both direct and indirect in nature and are categorized as labor, permanent materials, specific plant, equipment rental and supplies and expenses.

Labour cost is a function of the number of men working at any time during the installation component. The number of men working is specified by inputting shift productivity rate and rate of shift quantity placement. The composition of the shift's work week including days per week worked, regular and overtime hours is considered. Hourly labor wage rates per man would include base wage costs plus benefits and may or may not include other charges such as overhead and profit.

The remaining cost elements of the operation; permanent materials, specific plant, equipment rental and supplies and expenses, can be represented effectively by three cash flow types. The first type is lump sum payments occurring at only one specific point in time during the operation. This would include such items as payments for equipment and materials needed by the operation. Second are uniform cash flows occurring over a time period of the operation. Equipment costs will be the main item modeled by the uniform cash flow. The third cash flow type is costs that accrue as a function of quantity placed. Materials and operation and maintenance costs are items that can be established on a cost per unit placed basis.

As many items as necessary can be entered for each of the three cash flow types. The summation of the cash flows for each of the five cost elements provides the operation constant dollar cash flow profile. In the next section attention is returned to the total activity and its cash flow.

5-5.1 Operation Duration

A corollary to the above operation description is that of direct use of equation (5.1) to solve for operation duration. This approach is more appropriate when manpower loading is of known composition and magnitude. An operation duration is generated based on time normalized labor and productivity profiles. Productivity, P(t), is modeled by a quadratic while manpower, M(t), is modeled by the beta distribution which is used in turn to create the labor useage profile, L(t). With total work quantity known, Q(To), iterative techniques can be used to solve for operation duration, To. The addition of operation duration calculation increases the flexibility of the previously described generic operation model.

5-6 GENERIC ACTIVITY MODEL

The operation model described produces a constant dollar cash flow profile for an operation relative to operation time. To go to the activity all that is required is to transform the flows from operation to activity time. This is a rather simple procedure as outlined in FIG. 5-4.

Each operation in the activity is assigned a starting date in terms of activity time. Using this start date operation cash flows are converted to flows occurring in activity time.

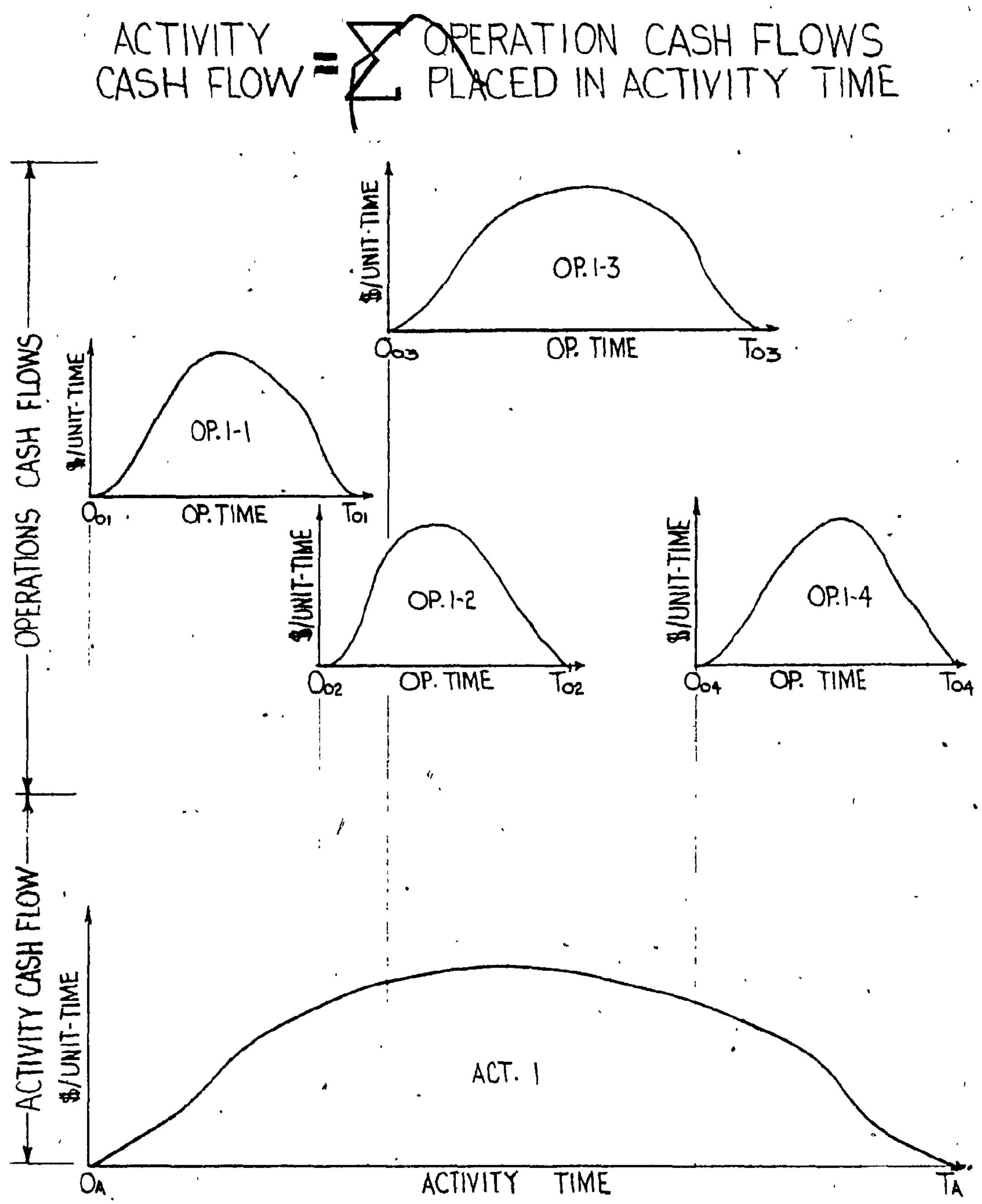


FIG. 5-4
ACTIVITY MODEL CONCEPT

The activity model allows for the inputting of costs not assignable to individual operations of the activity, but which are attributable to the entire activity. Mobilization costs are the major item that must be accounted for although there may be other significant costs such as procurement package prepayments. To account for these the model allows inputting costs associated with the entire activity as lump sum costs and uniform cash flows.

Time transformation applied to each operation gives operation cash flows in terms of activity time. Costs attributable to the entire activity are also in activity time. By summing the rate of cash flows occurring over each time unit of the activity the overall activity constant dollar cash flow profile can be constructed.

5-7 STEPS IN THE ACTIVITY MODEL

The generic requirements of the Micro Model (Activity Model) have been described in detail in the preceding sections. In the following a step by step use of the model is presented explicating what the model entails. Corresponding diagrams and equations are provided in FIG. 5-5 to aid clarification.

Steps provided are for a simplified activity. The activity is composed of one operation only. All costs incurred are attributable to the operation itself. The operation will be composed of one labor shift only. Assumptions made are for simplication of presentation and in no way are rigid restraints of the generic activity modeling concepts. Any assumptions used by the hybrid model developed from the overall generic modeling concepts were felt to be realistically justifiable.

STEP 1

The first requirement of the selected model is the entering of duration estimates. Operation duration, To, is entered as is the time at which the operation is slated to begin in the activity, Oo.

STEP 2

Estimated labor operation installation productivity rates over fixed time intervals of the operation duration are entered by the user. The productivity values entered must account for all project specifics. To these discrete input data points the model fits a "best fit" quadratic equation using least squares fitting of discrete points. This equation establishes the operation shift productivity as a continuous function of time, P(t) $Oo \leq t \leq To$. Values entered for productivity must account for all project specifics including assumptions about peak manpower, use of shift work and/or overtime, weather conditions, learning curve effects, etc.

STEP 3

Estimated cumulative quantity placements, Q(t), versus operation time are entered by the user. The values entered are fit by the model to a "best fit" beta curve. This gives both the cumulative placement, Q(t), and rate of placement, q(t), as continuous functions of operation time, $0 \leq t \leq T_o$.

STEP 4

The labor useage profile, L(t), is found by the application of equation (5.4) in the model.

STEP 5

The regular and overtime composition of unit time are entered for the shift by the user.

STEP 6

The model solves for the manpower resource profile, M(t). If the profile is acceptable to the user no alterations to the input of the previous steps are required. If modifications are needed a return must be made to the input step that is to be altered.

STEP 7

The labor cash flow profile is found by the user providing regular and overtime wage rates. Applying these inputs to the established manpower resource profile, M(t), the model gives operation labor cash flow during the installation phase.

STEP 8

Lump sum costs occurring during the operation are entered. This can include specific costs of set-up for the operation as well as other discrete payments such as procurement package payments. Both the time of occurrence, in operation time, and amount of lump sums are entered.

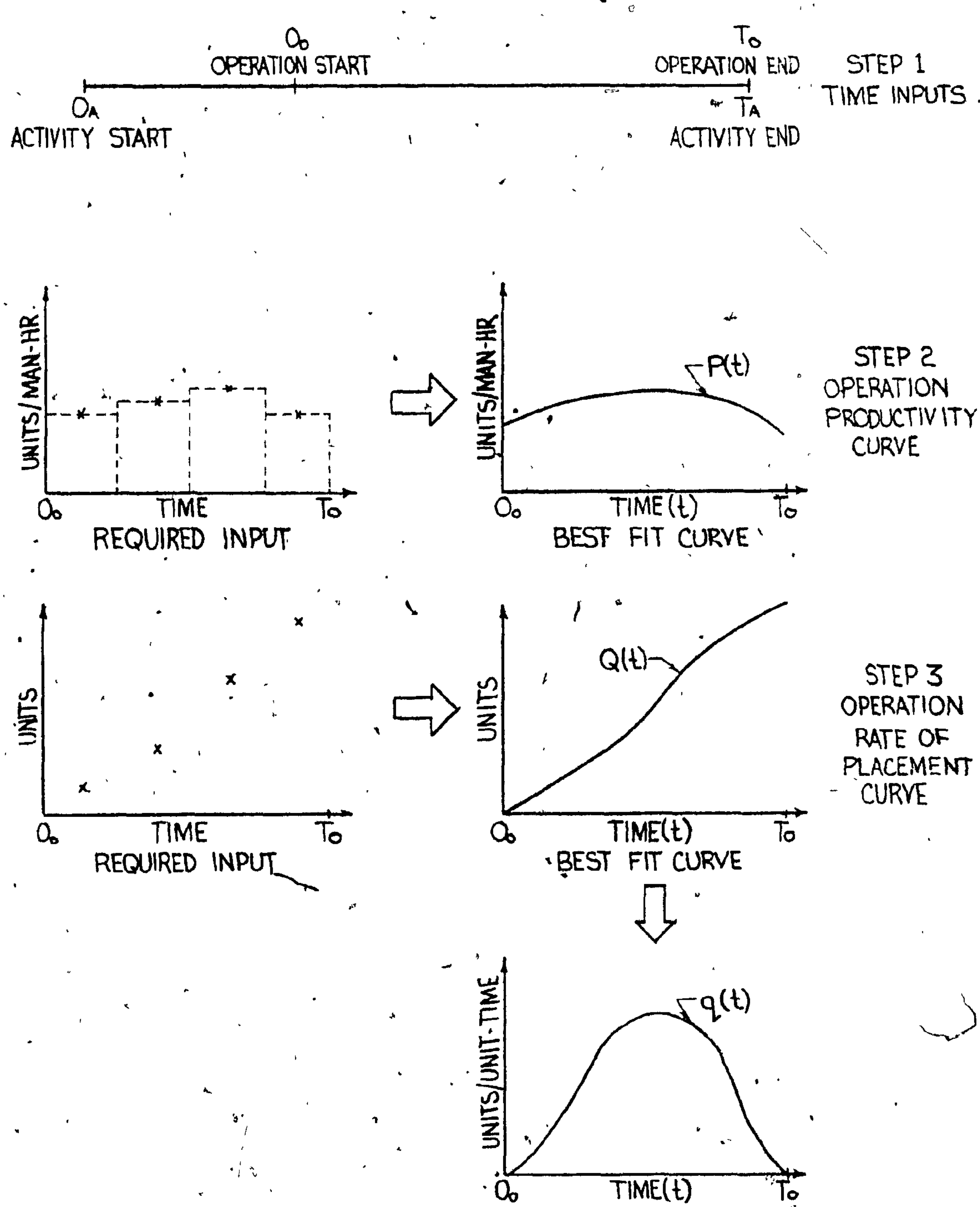
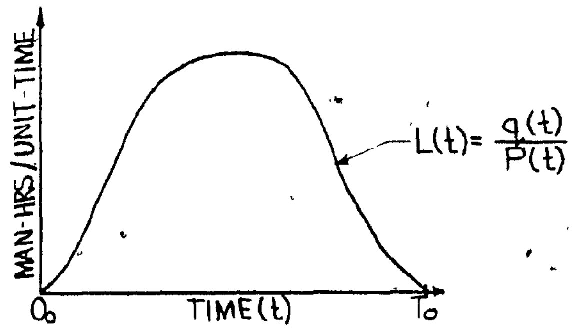


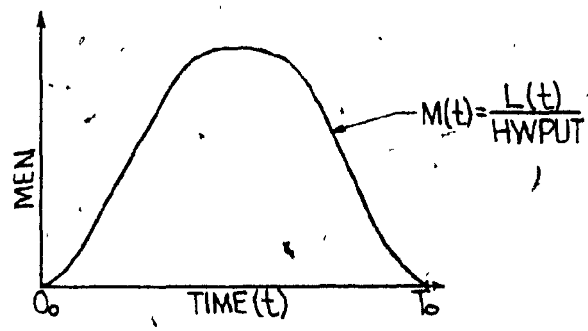
FIG.5-5
ACTIVITY MODEL STEPS



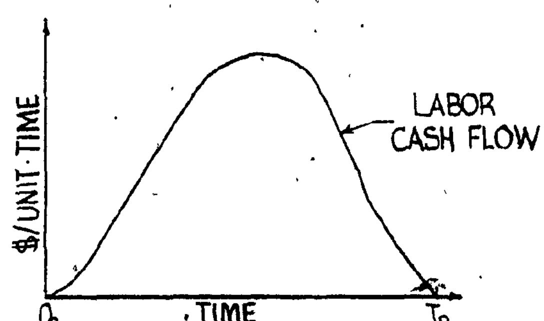
STEP 4
LABOR USEAGE
PROFILE

$$HWPUT = \frac{\text{DAYS}}{\text{UNIT TIME}} \times \frac{\text{HOURS WORKED}}{\text{DAY}}$$

STEP 5
HOURS WORKED
PER UNIT TIME



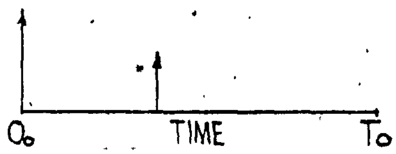
STEP 6
MAN POWER
PROFILE



STEP 7
LABOR CASH
FLOW PROFILE

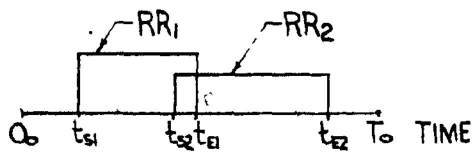
$$\text{LABOR COST} = \int_{O_0}^{T_0} M(t)\,(\text{REGULAR HRS.} \times \text{REGULAR RATE} + \text{OVERTIME HRS.} \times \text{OVERTIME RATE})\,dt$$

FIG. 5-5 CONT'D



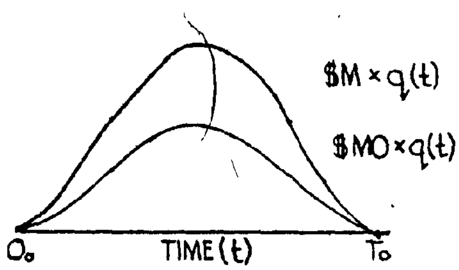
LUMP SUM COST = $\sum$ LUMP SUM FLOWS

STEP 8
LUMP SUM
CASH FLOW



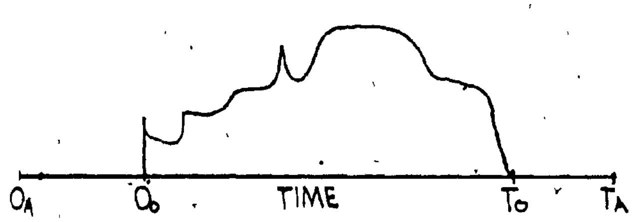
UNIFORM FLOW COST = $\sum_{n} RR_n(t_{En} - t_{sn})$

STEP 9
UNIFORM CASH
FLOW PROFILE



PLACEMENT DEPENDENT COST = $(\$M + \$MO)\int_{O_o}^{T_o} q(t)\,dt$

STEP 10
PLACEMENT DEPENDENT
CASH FLOW PROFILE



STEP 11
OVERALL OPERATION
CASH FLOW PLACED
IN ACTIVITY TIME

FIG.5-5 CONT'D

STEP 9

Uniform cash flows accruing to the operation include the cost of equipment. Rental rates per unit time, time when uniform cash flows begin in the operation and length of time uniform cash flow continues are entered for each uniform cash flow occurrence in the operation.

STEP 10

The final operation cash flow type are those dependent on rate of work completion, q(t). This includes such items as material costs, $M, and maintenance costs, $MO, which are established and entered as a cost per unit quantity placed.

STEP 11

The final step in the model is the production of the operation constant dollar cash flow. This is achieved by summing the cash flows derived for each of the three cash flow types. Operation cash flow is then converted into activity time and summed with any cash flows attributable to the total activity to give the overall constant dollar activity cash flows.

5-7.1 Operation Duration Calculation

As mentioned previously, it may be more appropriate at times to place restrictions on the labor profile and allow the operation duration to vary. When this is the case, additional steps must be added prior to Step 1 of the activity model.

STEP A

Estimated labor productivity rates are entered over the normalized duration of the operation. A "best fit" quadratic is calculated based on the inputted points (see FIG. 5-6).

STEP B

Estimated manpower values are entered by the user over the normalized duration. A "best fit" beta distribution is fitted to this data (FIG. 5-6).

STEP C

This step involves the calculation of hours worked per unit time, HWPUT, as provided in Step 5 of the activity model.

STEP D

Labor useage, L(t), is defined by the relation;

$$L(t)=M(t)\cdot HWPUT.$$

STEP E

Operation duration, To, is solved for iteratively using equation (5.1).

STEP F

"Best fit" beta parameters are calculated to fit both the cumulative placement, Q(t), and rate of placement, q(t).

With the results from these additional steps, the activity model as presented in the preceding section can be used. Operation duration calculated in Step E is used in Step 1. In Step 2, the same data is entered for productivity as in

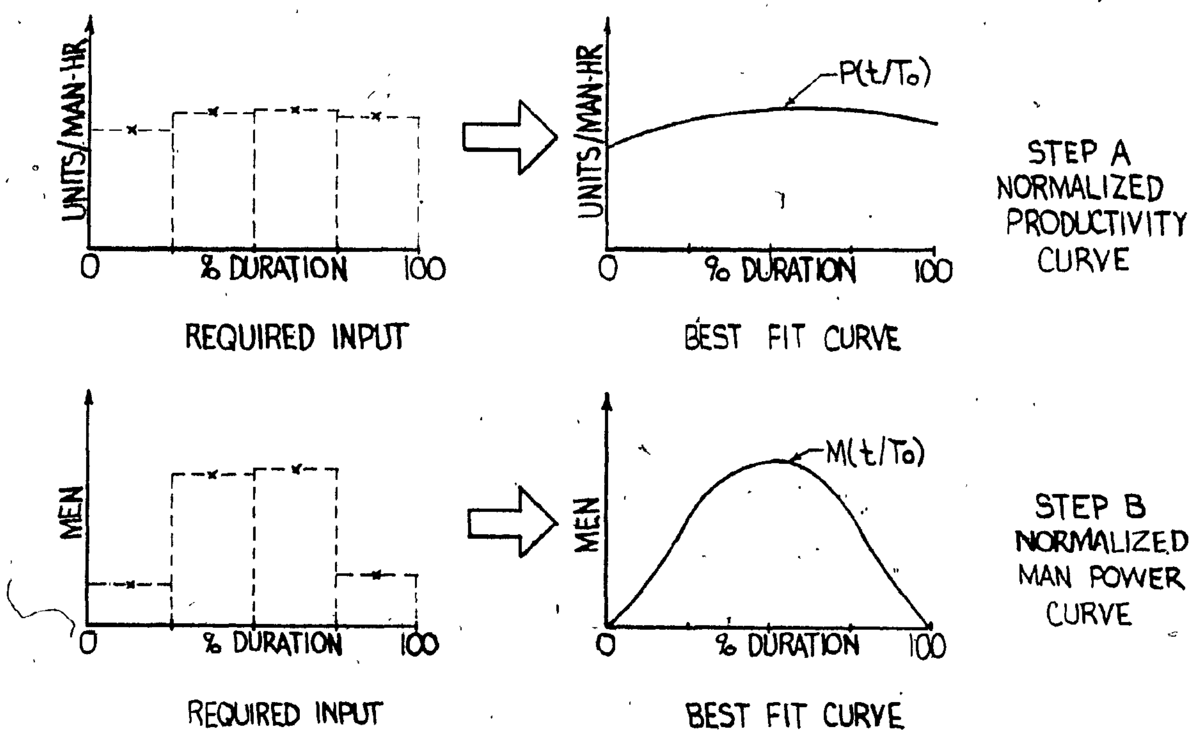


FIG. 5-6
INPUT FORMAT FOR
OPERATION DURATION CALCULATION

Step A. The "best fit" beta parameters calculated in Step F are entered directly in Step 3. The manpower profile results of Step 6 will match the shape and magnitude specified by the entries of Step B. Steps 7 through 11 of the activity model remain unchanged.

5-8 SUMMARY

The activity model in conjunction with operation duration calculation constitute the Micro Model. A detailed step by step construction of the model was provided. The basic model concepts presented are valid whereas chosen model specifics may be modified to fit individual project or company requirements.

The concepts presented are easily extendable from the activity level to the project level by summing the individual activity cash flows in project time. The resulting project cash flow can then be analyzed at the project level as presented earlier in this work. The model allows determination of the actual cost of crashing a project schedule to learn if the project level breakeven curve can be bettered.

The Micro Model provides a tool for preliminary budget analysis as its inputs are relatively simple in composition. The model aggregates these inputs into a complex result. As more project specifics are obtained the inputs can be altered and incorporated in the model. An important feature is the capability of using the model in a "what if" approach allowing sensitivity analysis at all levels. Some of the assumptions made in the specific model mean a rather limited analysis at present. The model can become more complete and versatile by future addition of flexibility.

The Micro Model shows how activity and, therefore, project level cash flow profiles are created and where and how they can be altered.

CHAPTER 6

MICRO MODEL ANALYTIC STUDIES

In this Chapter the versatility of the Micro Model programs are explored through several examples. The first example deals with the detailed preparation of one activity in the construction of a dam. In this example a large degree of project and activity work breakdown has been employed. Example two considers the use of the model on a crude project breakdown basis. Here analysis will be performed with an eye to establishing the best method of performing an activity. This would be representative of very preliminary project analysis where input information is extremely limited. Thirdly, the model will be used as a sensitivity tool on two of the results of example two in examples three and four. In these examples, model output variations will be explored for various productivity profiles.

6-1 STOCKPILING AGGREGATES FOR HYDROELECTRIC DAM: EXAMPLE 1

In preparing a project cash flow each project activity must be considered. This example looks at one activity in the construction of a hydroelectric facility. The activity is the stockpiling of aggregate required for the production of concrete. The purpose of this example is to illustrate the basic use of both programs of the Micro Model. In this example, crew sizes are fixed so that the first program of the model must be used to determine operation duration and required rate of placement profiles. These results are carried forward to the second program where activity duration, cash flow and total constant dollar cost are found. Descriptions and data for the example are based on information given for a fictitious dam estimate in reference 46.

Stockpiling of aggregate requires a quarry site to be established, cleared and made operational. Rock is removed from the quarry face by blasting techniques. Removed rock is then loaded and hauled along a specially constructed road to the aggregate plant. At the plant the rock is crushed and the aggregate stockpiled for use by the concrete mixing plant.

Quarry production rates are dependent on the rate at which concrete in the dam is to be poured, aggregate plant processing rate capabilities and amount of room available for stockpiling.

The activity is subdivided into four operations:

1) Quarry development

2) Drill and shoot.
3) Load and haul to aggregate plant.
4) Operation of aggregate plant.

Each operation was selected so as to be definable, convenient and measurable.

Total quantity of aggregate required is 1,480,222 tons. Concrete placement rates are scheduled to begin slowly but because of aggregate stockpiling capabilities a fairly constant aggregate removal and production rate can be used.

Each of the operations is now considered in detail for the required inputs to the model.

Operation 1-Quarry Development

Quarry preparation and setup begins the first week of the activity and is estimated to take five weeks. Over this period $15,000 will be spent on labor and an additional $15,000 on miscellaneous supplies, equipment and materials. The total $30,000 cost is spread evenly over the five week duration of the operation. This will be assigned to the overall activity rather than an individual operation.

Operation 2-Drill and Shoot

Drilling and shooting is set to commence in the fifth week of the activity. Labour classifications and wages of the 8 man drill and shoot crew are the following for an eight hour shift -

LABOR	WAGE/SHIFT
2-drillers	$144.44
2-chuck tenders	135.50
1-compressor operator	93.86
1-drill doctor/grinder	88.18
1-powder truck driver	95.00
1-powder man	72.22
8	$629.20

Total wages per crew shift are $629.20 for an average hourly wage of $9.38 per man-hour. Eight hour shifts five days a week are to be used.

Past company records indicate the following productivity rates -

PERCENTAGE SPAN OF OPERATION DURATION	AVERAGE PRODUCTIVITY OVER TIME SPAN
0-20%	52.0 tons/man-hr.
20-40	57.0
40-60	60.5
60-80	58.5
80-100	54.5

Equipment used includes jack hammers, bore crawlers, compressors and powder trucks costing $1891.70 per week. Maintenance and operation of drills, compressors, trucks and miscellaneous cost $0.20 per ton of quarry rock removed.

Lump sum costs include equipment mobilization of $2,500 in the first week and the $1,000 cost of a compressor housing in the second week of the operation.

Operation 3-Load and Haul to Aggregate Plant

Haul road construction begins the first week of the activity and will cost $40,000. This cost is incurred as five equal weekly lump sum costs of $8,000 each which are assigned to the overall activity rather than the operation.

Operation crew size remains constant and is as follows -

LABOR	WAGE/SHIFT
1-foreman	$ 99.64
1-truck spotter	67.75
1-shovel operator	289.72
1-bulldozer operator	110.23
4-dump truck operators	391.68
1-general laborer	49.00
9	$1008.02

The average hourly wage is $14.00 per man-hour. Hauling is to be carried out 5 days a week, 8 hours a day.

Estimated productivity over the operation phase is as follows -

PERCENTAGE SPAN OF OPERATION DURATION	AVERAGE PRODUCTIVITY OVER TIME SPAN
0-20%	46.0 tons/man-hr.
20-40	51.5
40-60	51.5
60-80	49.5
80-100	47.0

Operation equipment includes bulldozers, dump trucks and diesel shovels costing a weekly rate of $4229.70. Maintenance and operation of the equipment, road and miscellaneous costs $0.12 per ton of rock hauled. Operation mobilization is set at $6,700.

Operation 4-Aggregate Plant

The final activity operation is also run for one shift per day five days a week. Plant labor is as follows -

LABOR	WAGE/SHIFT
1-foreman	$ 99.64
1-primary crusher operator	84.70

1-operator for other crushers	$ 84.70
1-screens and classifiers operator	84.70
4-oilers	301.64
2-general laborers	135.50
1-welder	88.18
2-mechanics	176.36
13	$1055.42

Average hourly wage rate for the crew is $10.15 per man-hour.

Productivity rates are expected to be as follows -

PERCENTAGE SPAN OF OPERATION DURATION	AVERAGE PRODUCTIVITY OVER TIME SPAN
0-20%	31.5 tons/man-hr.
20-40	34.0
40-60	35.5
60-80	34.5
80-100	32.0

Equipment costs include only the plant and this has been charged to a previous activity. Maintenance and operation of the plant is $0.16 per ton of rock crushed.

RESULTS

PART 1

The results of the runs for the first program of the Micro Model are given in the following three pages. Quarry development duration is already known so that a run for this operation is not performed. The three remaining operations are run to calculate the operation durations given that operation crew sizes remain constant. The printout provides the operation duration in weeks and the best fit beta parameters for rate of work placement. Also listed are the best fit quadratic parameters for normalized productivity. Best fit parameter values and durations are required for use of the second program of the Micro Model.

With operation durations known, the activity level network can be constructed as shown in FIG. 6-1. The operations start dates in terms of activity time are required by the second program.

```
***************************************************

              OPERATION DURATION

***************************************************

  OPERATION-DRILL AND SHOOT

          PRODUCTIVITY VALUES ENTERED (UNITS/MANHR)
               52.000
               57.000
               60.500
               58.500
               54.000
            BEST FIT QUADRATIC GIVES
            PRODUCTIVITY= 47.587540+  0.464998T+ -0.004375T**2
            WHERE "T" IS % OF OPERATION DURATION

              R(1)= 47.5875400000
              R(2)=  0.4649978000
              R(3)= -0.0043749770

          MANPOWER VALUES ENTERED (MEN)
                8.000
                8.000
                8.000
                8.000
                8.000
THE BEST FIT BETA PARAMETERS FOR MANPOWER PROFILE ARE
          P=   1.0000
          Q=   2.0000

OPERATION DURATION IS   96.59 WEEKS

***************************************************
  THE BEST FIT BETA PARAMETERS FOR THE RATE OF
          QUANTITY PLACEMENT ARE
          P=   1.00575200
          Q=   2.01242200
***************************************************
```

```
***************************************************

          OPERATION DURATION

***************************************************

  OPERATION-LOAD AND HAUL TO AGGREGATE PLANT

          PRODUCTIVITY VALUES ENTERED (UNITS/MANHR)
               46.000
               51.000
               51.500
               49.500
               47.000
            BEST FIT QUADRATIC GIVES
            PRODUCTIVITY= 43.562450+  0.315002T+ -0.003125T**2
            WHERE "T" IS % OF OPERATION DURATION

              R(1)= 43.5624500000
              R(2)=  0.3150023000
              R(3)= -0.0031250220

          MANPOWER VALUES ENTERED (MEN)
                9.000
                9.000
                9.000
                9.000
                9.000
THE BEST FIT BETA PARAMETERS FOR MANPOWER PROFILE ARE
          P=  1.0000
          Q=  2.0000

OPERATION DURATION IS    93.89 WEEKS

***************************************************
 THE BEST FIT BETA PARAMETERS FOR THE RATE OF
          QUANTITY PLACEMENT ARE
          P=  1.00335200
          Q=  2.00647400
***************************************************
```

```
*****************************************************

              OPERATION DURATION

*****************************************************

  OPERATION-OPERATION OF AGGREGATE PLANT

          PRODUCTIVITY VALUES ENTERED (UNITS/MANHR)
               31.500
               34.000
               35.500
               34.500
               32.000
            BEST FIT QUADRATIC GIVES
            PRODUCTIVITY= 29.330320+  0.230716T+ -0.002232T**2
            WHERE "T" IS % OF OPERATION DURATION

             R(1)= 29.3303200000
             R(2)=  0.2307160000
             R(3)= -0.0022321590

          MANPOWER VALUES ENTERED (MEN)
               13.000
               13.000
               13.000
               13.000
               13.000
THE BEST FIT BETA PARAMETERS FOR MANPOWER PROFILE ARE
          P=  1.0000
          Q=  2.0000

OPERATION DURATION IS   96.60 WEEKS

*****************************************************
  THE BEST FIT BETA PARAMETERS FOR THE RATE OF
          QUANTITY PLACEMENT ARE
          P=  1.00286200
          Q=  2.00468300
*****************************************************
```

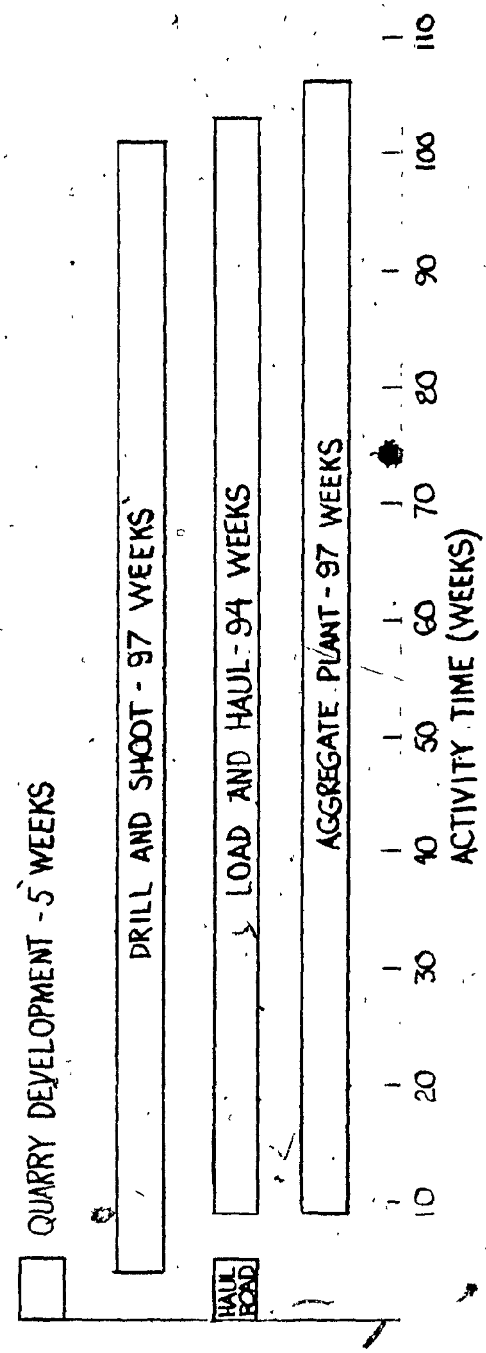


FIG. 6-1
EXAMPLE 1
ACTIVITY LEVEL NETWORK

PART 2

The second program of the Micro Model is now used to produce activity cash flow, activity labor profile and activity cost in terms of constant dollars. The computer output is listed on the following pages.

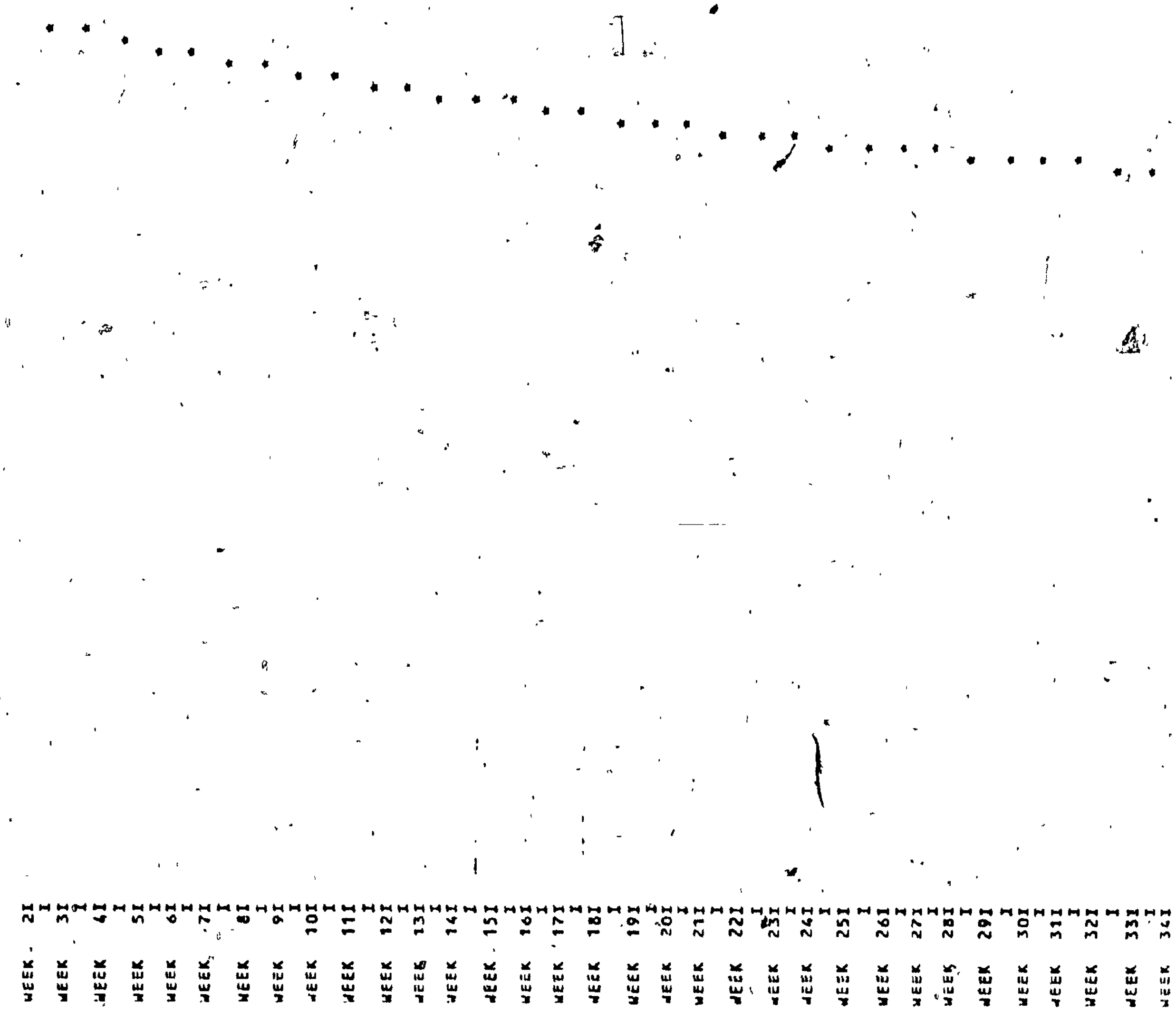
Costs associated with the overall activity are entered first. Then, each shift of each operation is considered. Appropriate time durations, productivity parameters, rate of placement parameters, wages and costs are entered. For each shift of an operation a manpower profile is provided. (Note that the graphical output of the labor profile is not constant due to round off errors).

After all data for the operations has been inputted, the overall activity cash flow is output in graphical and numerical formats. Total activity constant dollar cost is also listed. The activity labor profile is displayed graphically and numerically.

OVERALL

This example has shown the basic use of the two programs of the Micro Model as currently set up. The results of the model are valuable to the planning of a construction project (peak cash flow, peak manpower, activity cost etc.) and allow investigation of "what if" situations through variation in resource requirements at the activity level of analysis.

```
**************************************************

            ACTIVITY MODEL

**************************************************
ACTIVITY DESCRIPTION-STOCKPILING OF AGGREGATE

            ACTIVITY LUMP SUMS
            WEEK          AMOUNT            DESCRIPTION
              0        $       0.00

            UNIFORM COSTS OF ACTIVITY
            WEEKLY RATE      WEEK START      WEEKS          DESCRIPTION
            $   6000.00          1             5            QUARRY DEVELOPMENT
            $   8000.00          1             5            HAUL ROAD CONST.

  NUMBER OF OPERATIONS IN ACTIVITY= 3

  ** OPERATION- 1 DRILL AND SHOOT
     OPERATION  1 HAS  1 SHIFTS
        OVERALL OPERATION DURATION  97 WEEKS
        OPERATION STARTS IN WEEK   5 OF ACTIVITY

           SHIFT  1
            BEST FIT QUADRATIC GIVES
            PRODUCTIVITY= 47.587540+  0.464998T+ -0.004375T**2
            WHERE "T" IS TIME IN WEEKS

            TOTAL WORK UNITS   1480222.00
            RATE OF PLACEMENT GIVEN BY BEST FIT BETA CURVE
            WITH BETA PARAMETERS
              P=  1.0058
              Q=  2.0124

            DAYS PER WEEK WORKED 5.00
            REGULAR HOURS WORKED PER DAY  8.00
            OVERTIME HOURS WORKED PER DAY  0.00
            REGULAR HOURLY WAGE RATE $  9.83/MAN-HOUR
            OVERTIME HOURLY WAGE RATE $ 19.66/MAN-HOUR

            LUMP SUM COSTS
            WEEK          AMOUNT            DESCRIPTION
              1        $    2500.00         MOBILIZATION
              2        $    1000.00         COMPRESSOR HOUSINGS

            UNIFORM COST
            WEEKLY RATE      WEEK START      WEEKS          DESCRIPTION
            $  1891.70           1            97            EQUIPMENT

            COSTS PER UNIT PLACED
            COST/UNIT            DESCRIPTION
            $   0.20            SUPPLIES

                                               SHIFT/OPERATION MANPOWER
                             2                   4                   6                   8                  10
                             I                   I                   I                   I                   I
         TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT
         I
WEEK    1I
         I
```


WEEK 2
WEEK 3
WEEK 4
WEEK 5
WEEK 6
WEEK 7
WEEK 8
WEEK 9
WEEK 10
WEEK 11
WEEK 12
WEEK 13
WEEK 14
WEEK 15
WEEK 16
WEEK 17
WEEK 18
WEEK 19
WEEK 20
WEEK 21
WEEK 22
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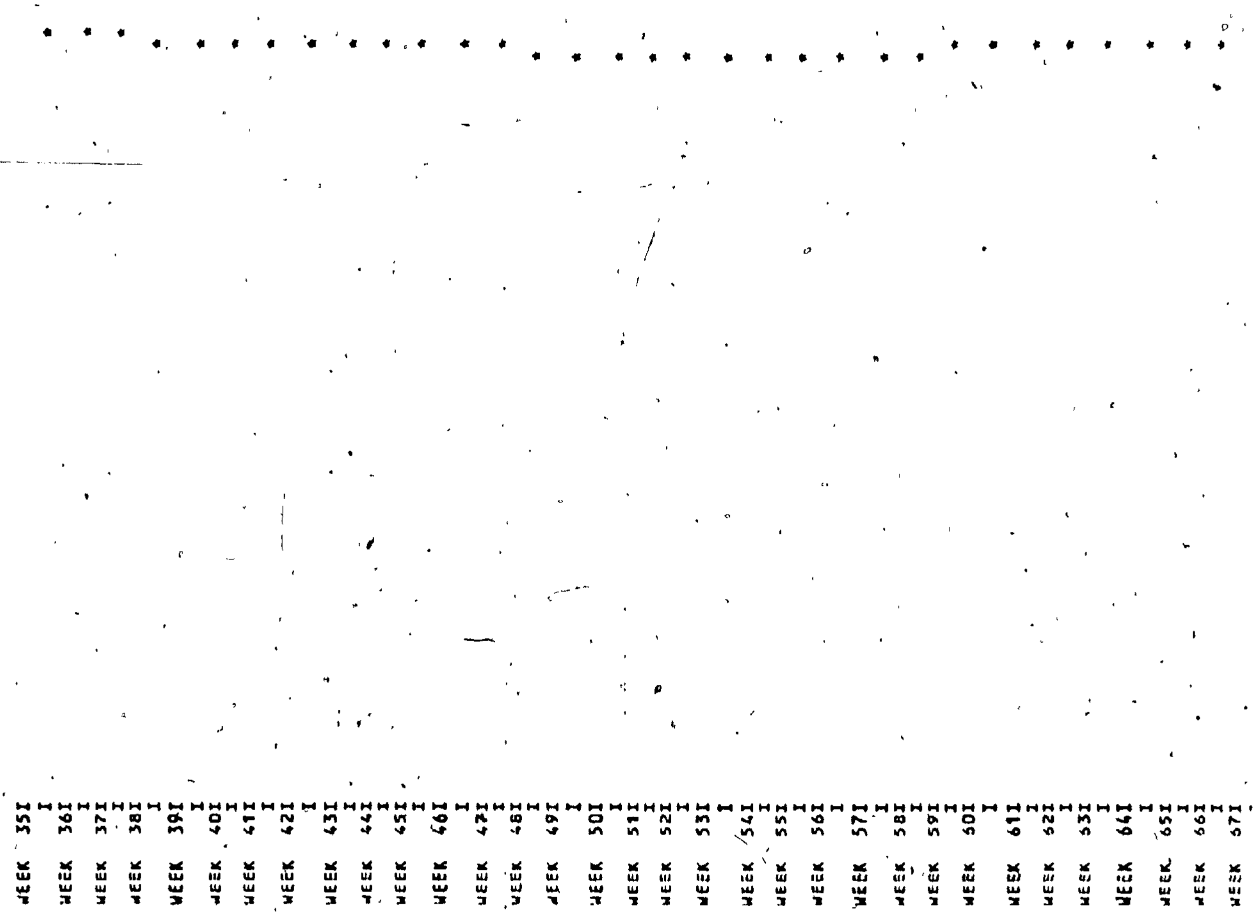
WEEK 32
WEEK 33
WEEK 34


WEEK 35I
WEEK 36I
WEEK 37I
WEEK 38I
WEEK 39I
WEEK 40I
WEEK 41I
WEEK 42I
WEEK 43I
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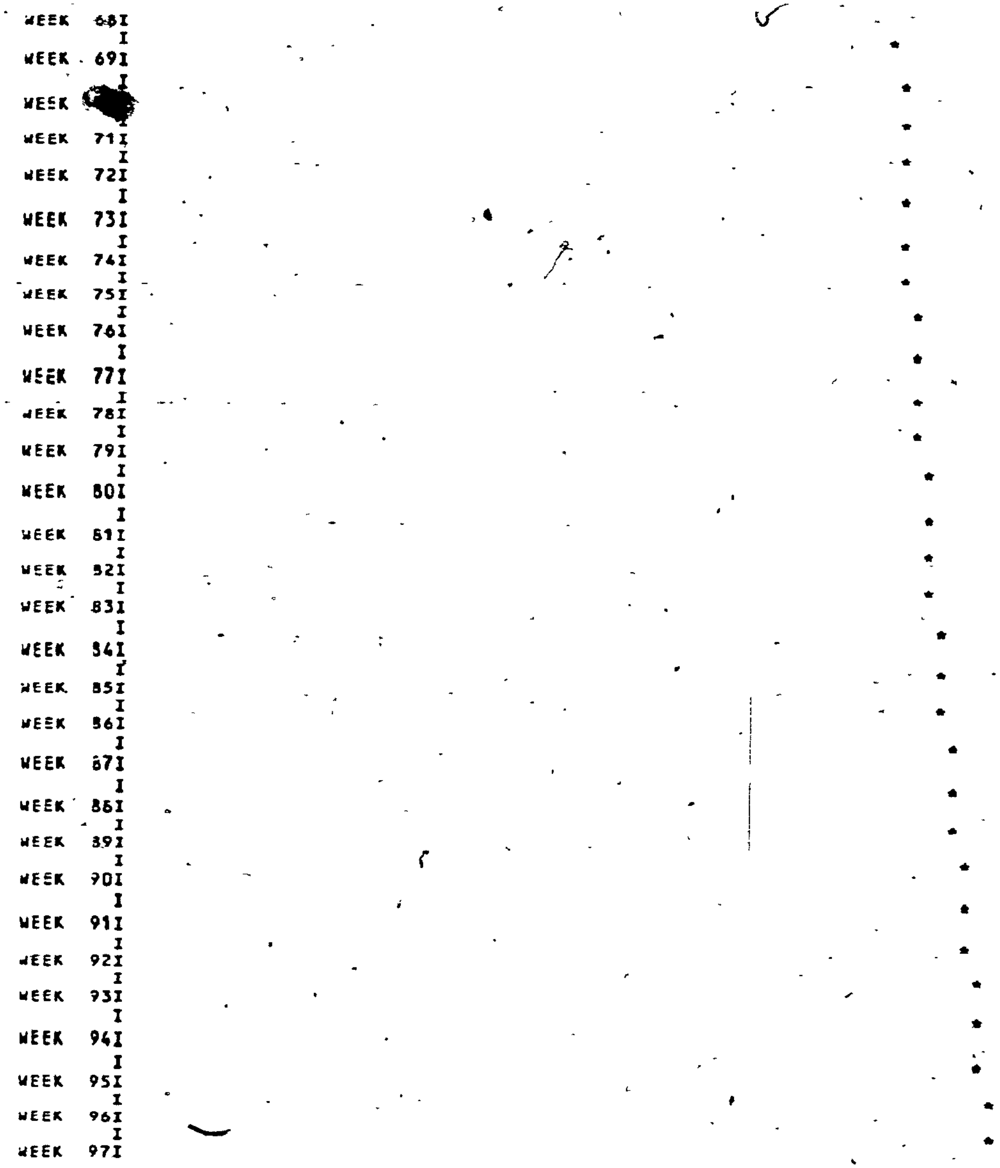
WEEK 66I
WEEK 67I



** OPERATION- 2 HAUL TO AGGREGATE PLANT
OPERATION 2 HAS 1 SHIFTS
OVERALL OPERATION DURATION 94 WEEKS
OPERATION STARTS IN WEEK 9 OF ACTIVITY

```
BEST FIT QUADRATIC GIVES
PRODUCTIVITY= 43.562450+  0.315002T+ -0.003125T**2
WHERE "T" IS TIME IN WEEKS

TOTAL WORK UNITS   1480222.00
RATE OF PLACEMENT GIVEN BY BEST FIT BETA CURVE
WITH BETA PARAMETERS
   P=  1.0034
   Q=  2.0065

DAYS PER WEEK WORKED 5.00
REGULAR HOURS WORKED PER DAY  8.00
OVERTIME HOURS WORKED PER DAY  0.00
REGULAR HOURLY WAGE RATE $ 14.00/MAN-HOUR
OVERTIME HOURLY WAGE RATE $ 28.00/MAN-HOUR

LUMP SUM COSTS
WEEK          AMOUNT          DESCRIPTION
  1      $    6700.00         MOBILIZATION

UNIFORM COST
WEEKLY RATE      WEEK START      WEEKS         DESCRIPTION
$   4229.70          1             96          EQUIPMENT

COSTS PER UNIT PLACED
COST/UNIT           DESCRIPTION
$   0.12             SUPPLIES
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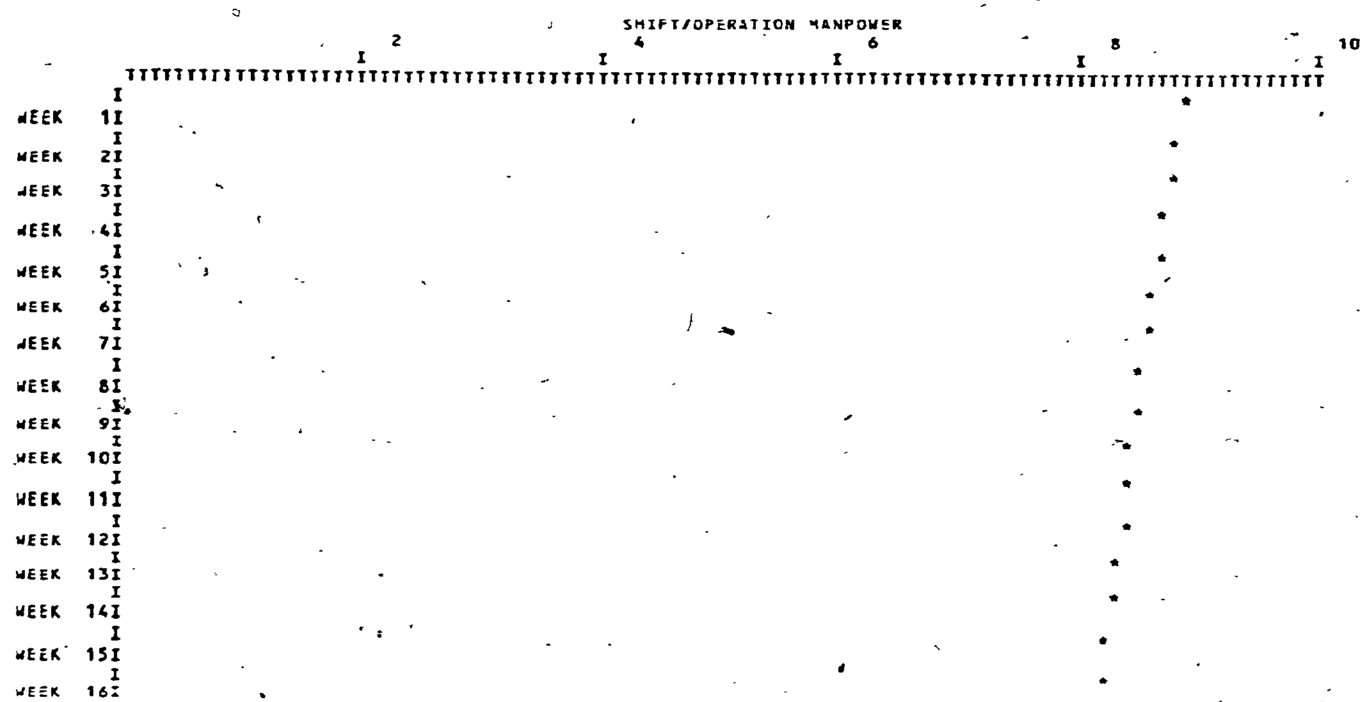

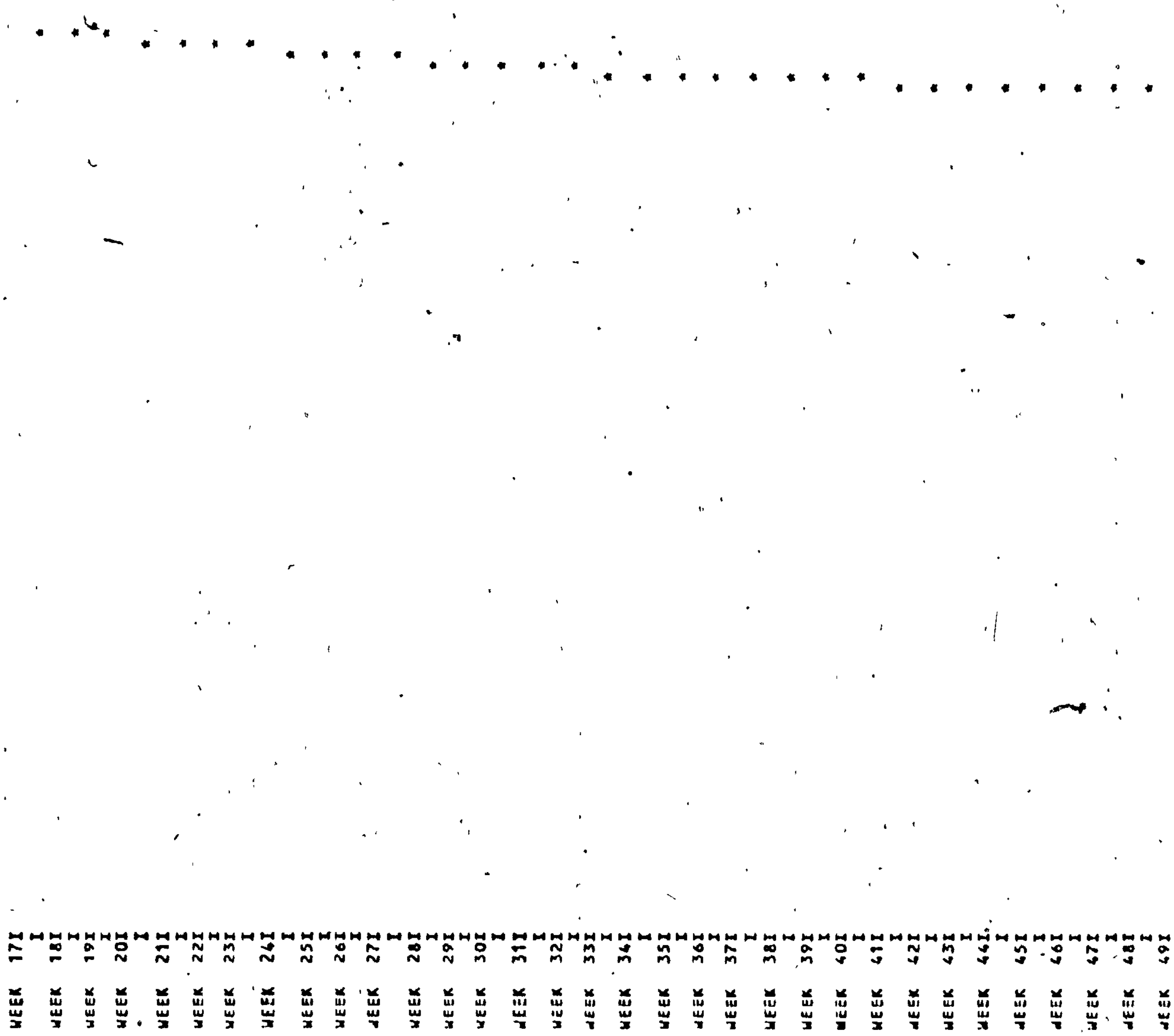
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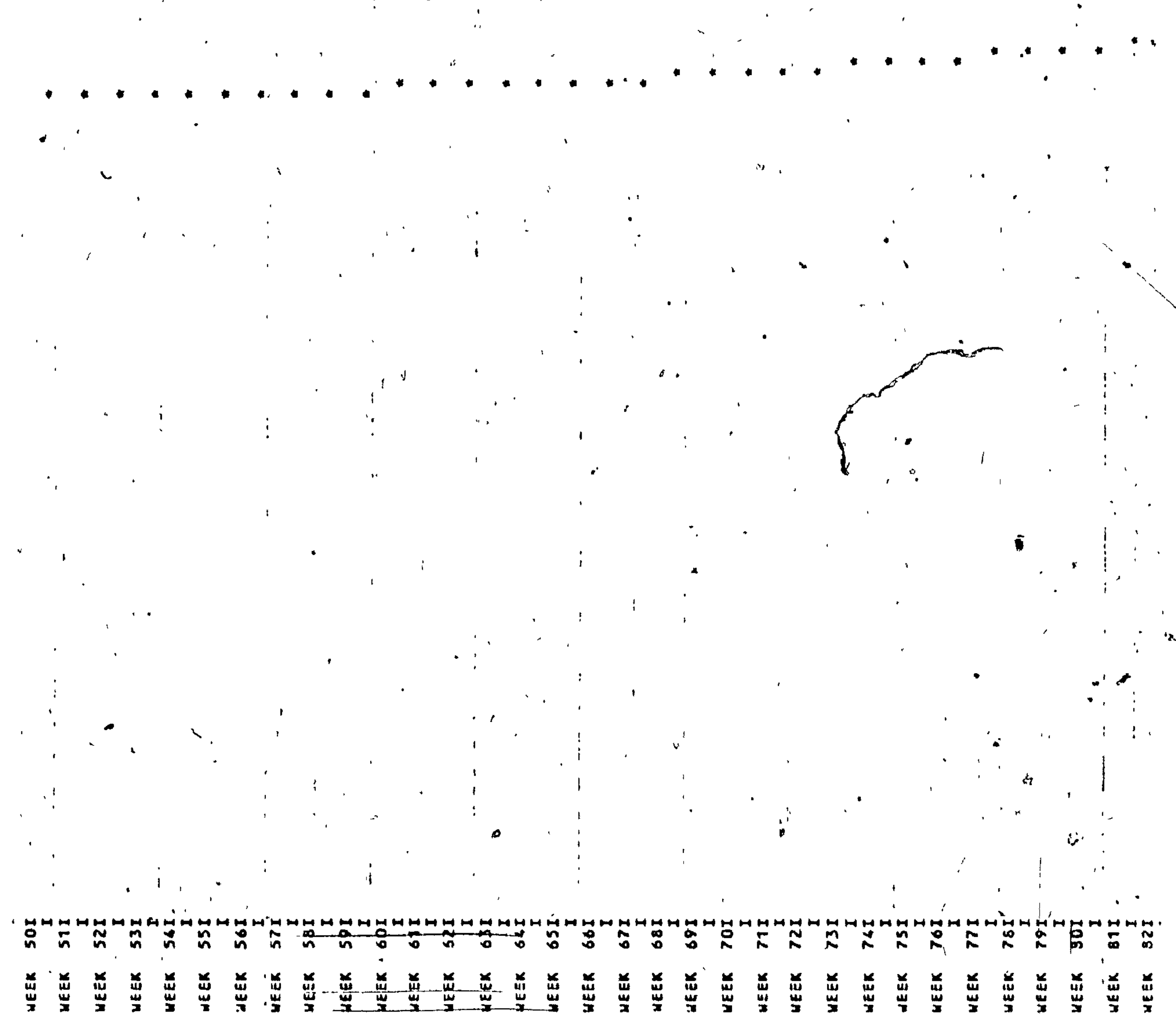
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 ** OPERATION- 3 OPERATION OF AGGREGATE PLANT
   OPERATION  3 HAS  1 SHIFTS
      OVERALL OPERATION DURATION  97 WEEKS
      OPERATION STARTS IN WEEK   9 OF ACTIVITY

         SHIFT  1
           BEST FIT QUADRATIC GIVES
           PRODUCTIVITY= 29.330320+  0.230716T+ -0.002232T**2
           WHERE "T" IS TIME IN WEEKS

           TOTAL WORK UNITS   1480222.00
           RATE OF PLACEMENT GIVEN BY BEST FIT BETA CURVE
           WITH BETA PARAMETERS
             P=  1.0029
             Q=  2.0047

           DAYS PER WEEK WORKED 5.00
           REGULAR HOURS WORKED PER DAY  8.00
           OVERTIME HOURS WORKED PER DAY  0.00
           REGULAR HOURLY WAGE RATE $ 10.15/MAN-HOUR
           OVERTIME HOURLY WAGE RATE $ 20.30/MAN-HOUR

           LUMP SUM COSTS
           WEEK              AMOUNT            DESCRIPTION
             0        $         0.00

           UNIFORM COST
           WEEKLY RATE       WEEK START      WEEKS            DESCRIPTION
           $     0.00             0             0

           COSTS PER UNIT PLACED
           COST/UNIT              DESCRIPTION
           $   0.16               SUPPLIES

                                                   SHIFT/OPERATION MANPOWER
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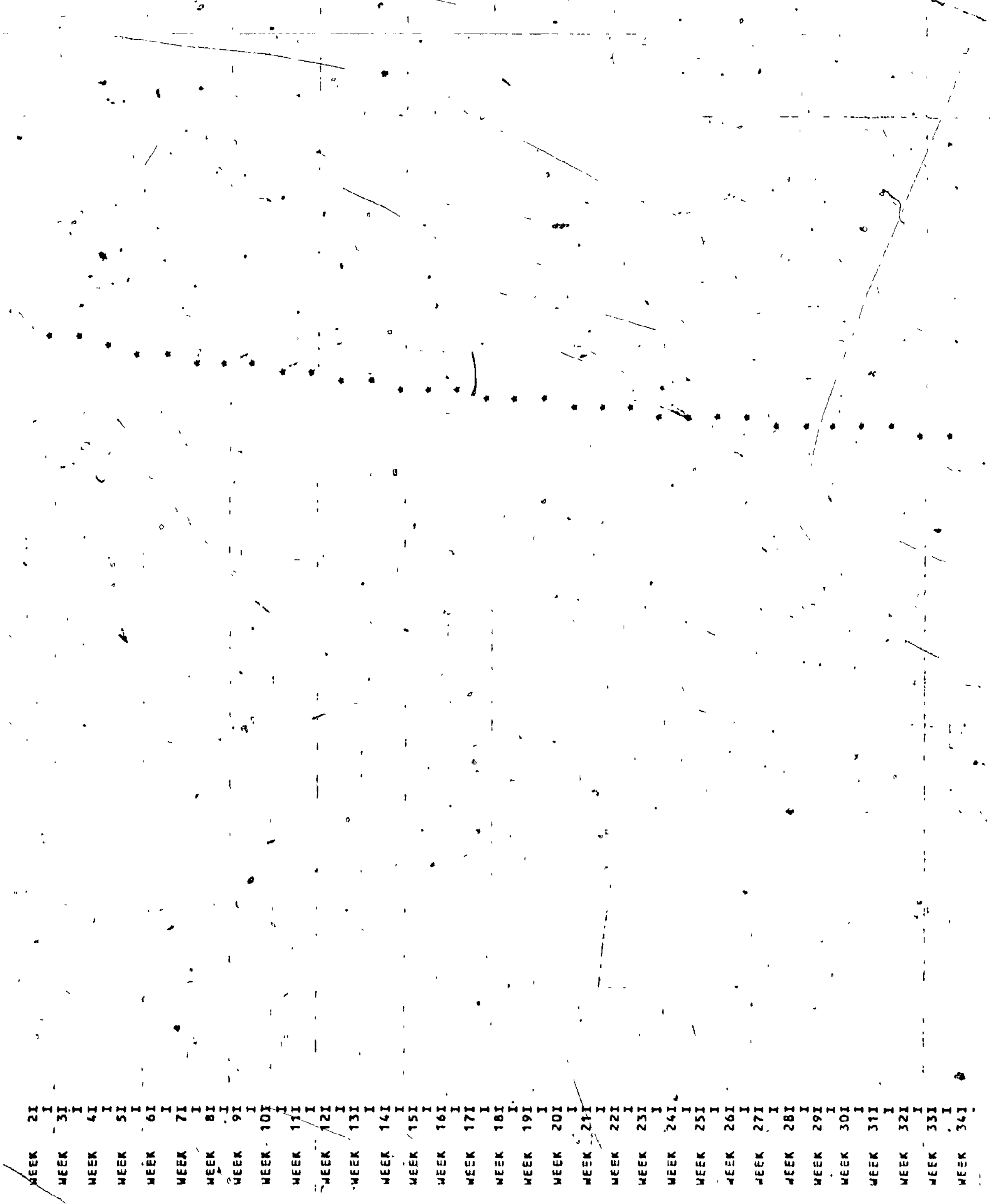
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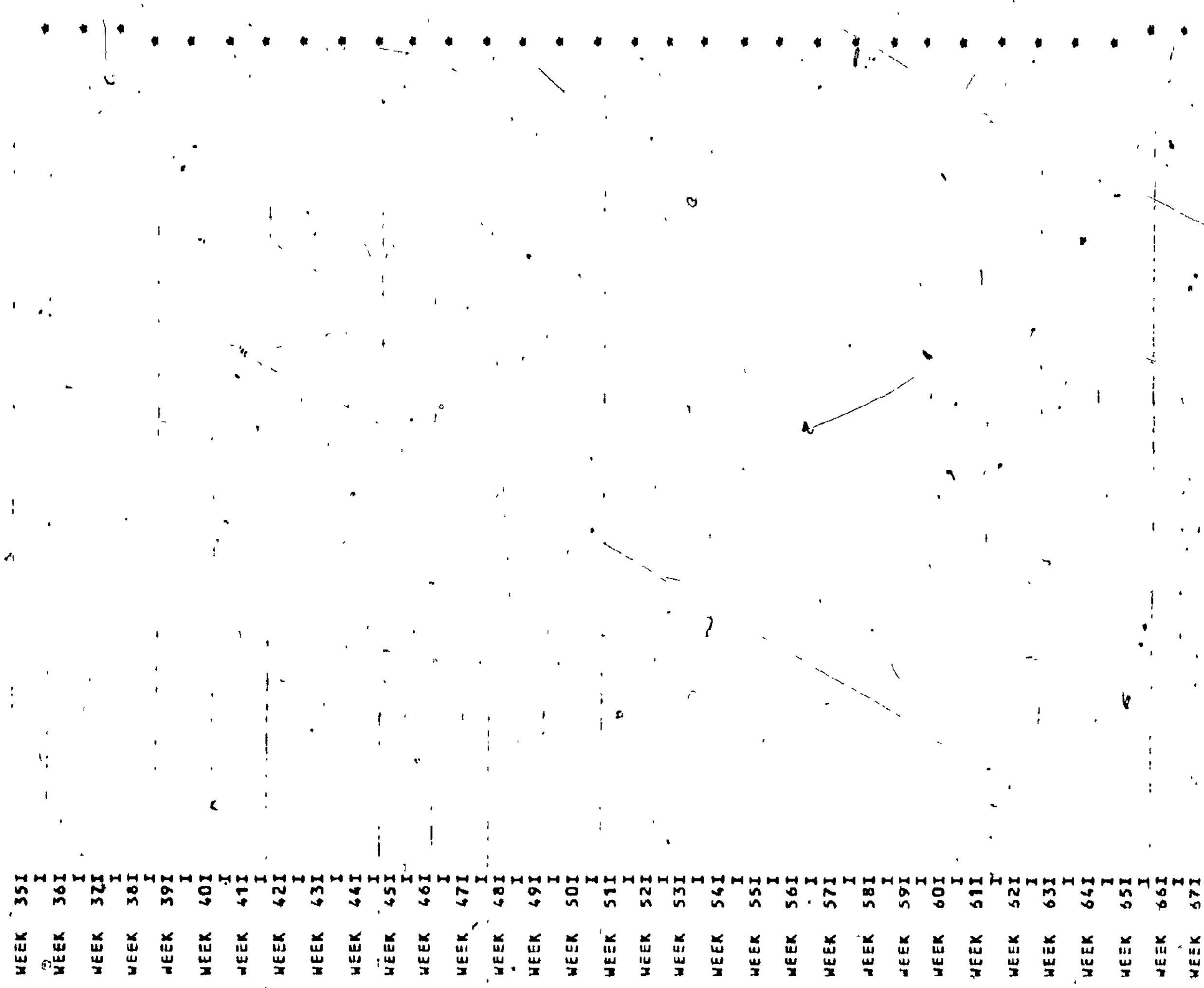
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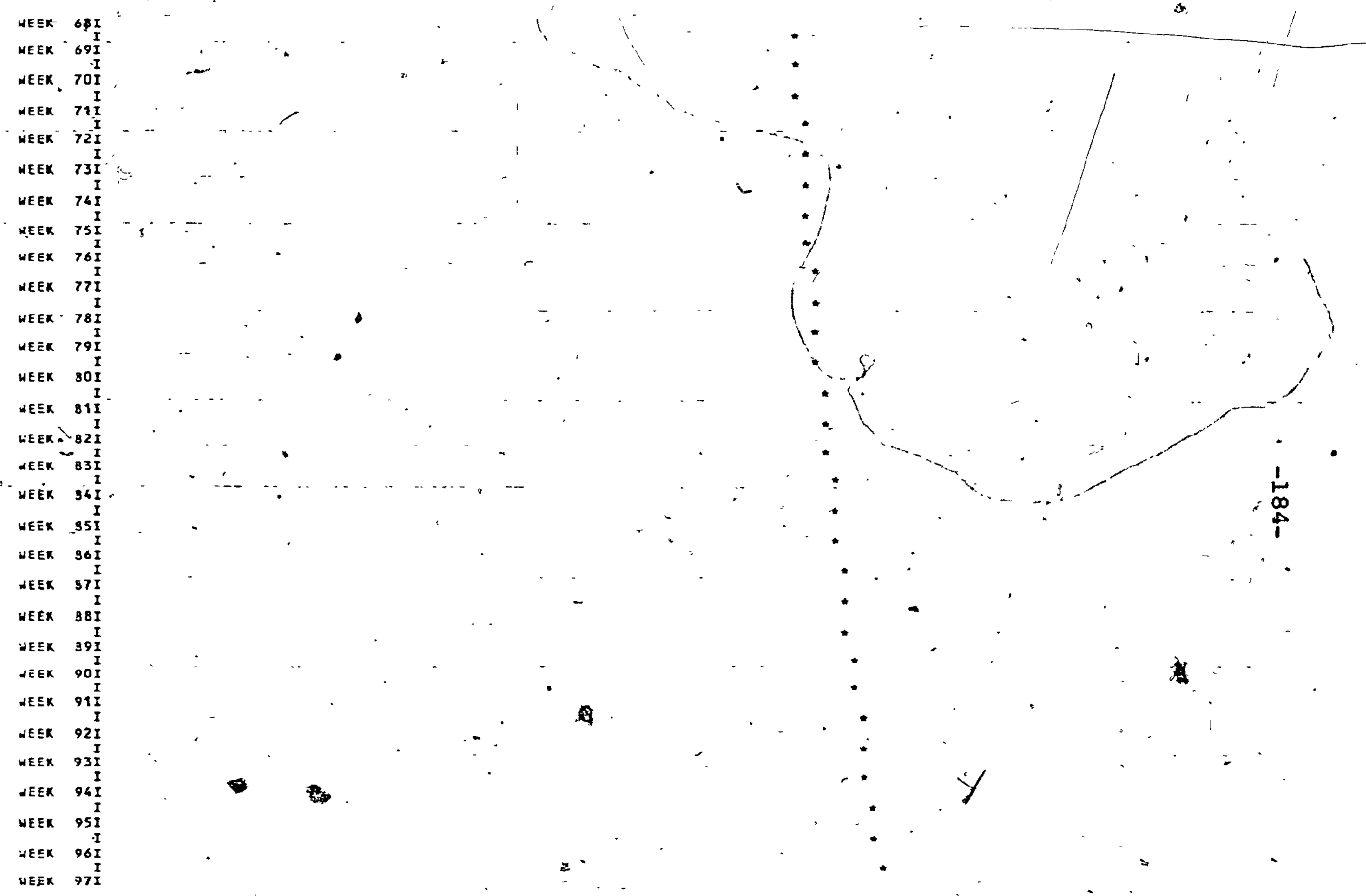


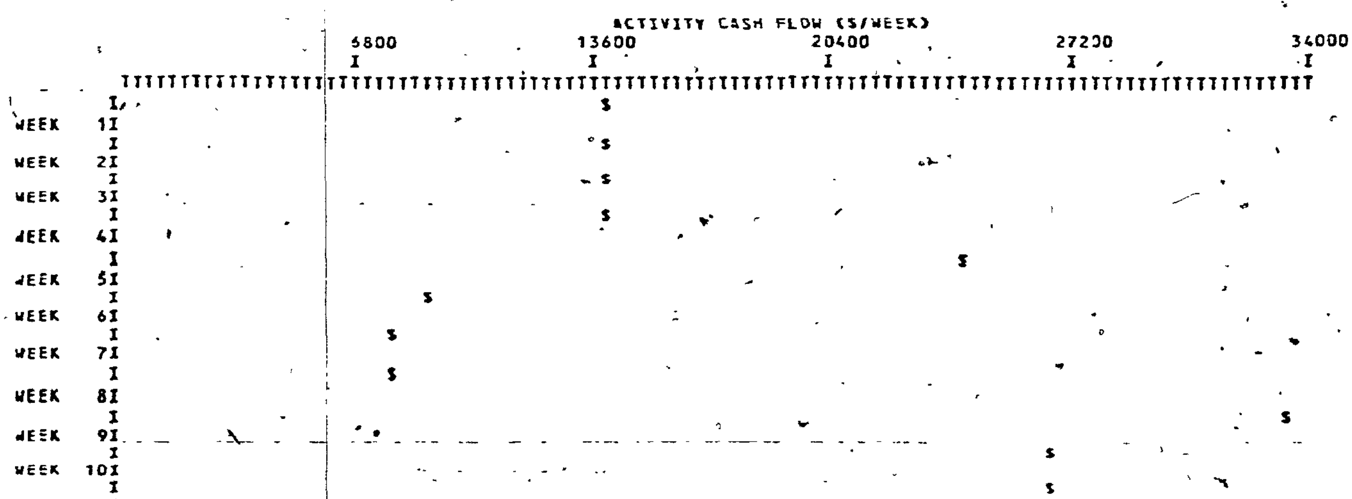
*****ACTIVITY CA.H FLOW*****

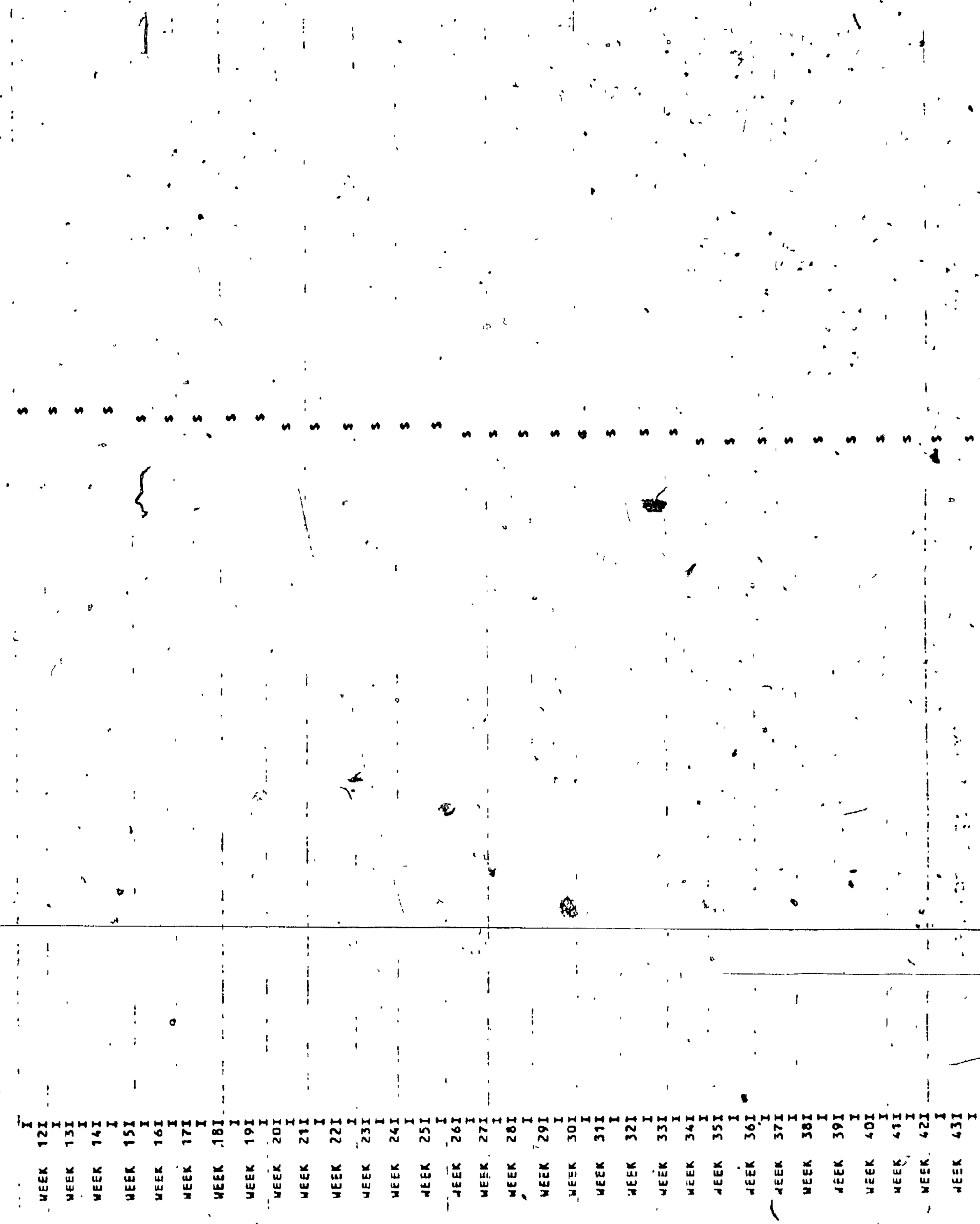
WEEK	$/WEEK
1	14000.00
2	14000.00

4	14000.00
5	24470.71
6	8979.52
7	7968.71
8	7952.77
9	33342.39
10	26597.57
11	26528.49
12	26453.96
13	26378.16
14	26302.69
15	26228.32
16	26155.45
17	26084.36
18	26015.14
19	25947.93
20	25882.71
21	25819.55
22	25758.42
23	25699.31
24	25642.23
25	25537.13
26	25533.99
27	25452.80
28	25433.52
29	25336.11
30	25340.55
31	25296.83
32	25254.87
33	25214.71
34	25176.26
35	25139.54
36	25104.48
37	25071.09
38	25039.33
39	25009.18
40	24980.64
41	24953.65
42	24928.22
43	24904.32
44	24881.94
45	24861.05
46	24841.66
47	24823.73
48	24807.26
49	24792.24
50	24778.65
51	24766.48
52	24755.74
53	24746.40
54	24738.46
55	24731.91
56	24726.77
57	24723.01
58	24720.64
59	24719.64
60	24720.02
61	24721.79
62	24724.93
63	24729.46
64	24735.36
65	24742.66
66	24751.37
67	24761.46
68	24772.94

70	24800.15
71	24815.93
72	24833.11
73	24851.74
74	24871.83
75	24893.38
76	24916.43
77	24940.96
78	24966.99
79	24994.56
80	25023.63
81	25054.29
82	25086.48
83	25120.27
84	25155.63
85	25192.58
86	25231.14
87	25271.32
88	25313.12
89	25356.52
90	25401.50
91	25448.06
92	25496.14
93	25545.66
94	25596.52
95	25648.54
96	25701.42
97	25754.72
98	25807.55
99	25858.24
100	25902.55
101	25922.49
102	18243.14
103	7390.93
104	7415.15
105	7432.48

TOTAL ACTIVITY COST $ 2502162.00

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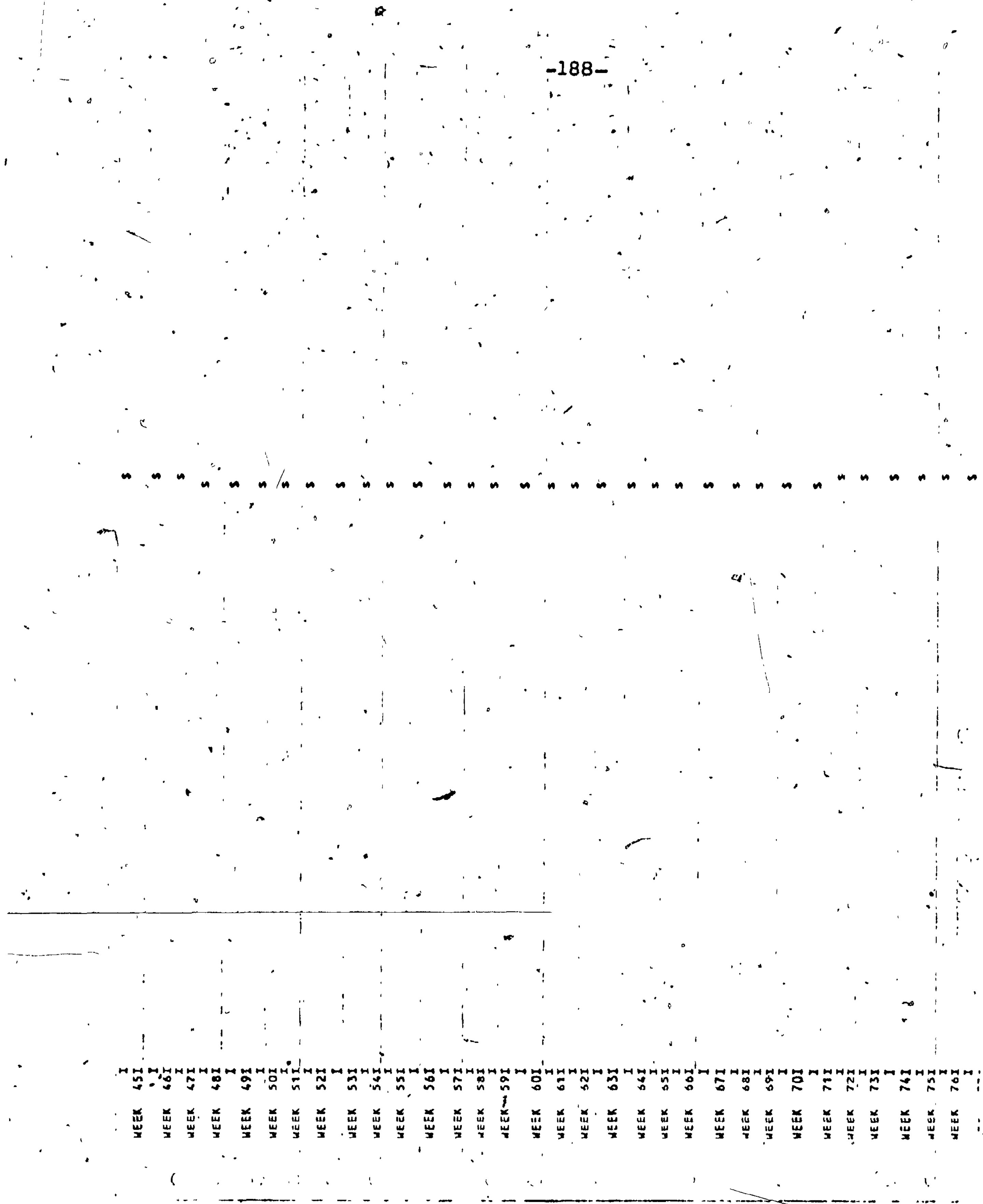
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*****ACTIVITY MANPOWER*****

WEEK	MEN
1	0.0
2	0.0
3	0.0
4	0.0
5	7.8

7	7.8
8	7.7
9	29.4
10	29.2
11	29.1
12	28.9
13	28.7
14	28.5
15	28.3
16	28.2
17	28.0
18	27.8
19	27.7
20	27.5
21	27.4
22	27.2
23	27.1
24	27.0
25	26.9
26	26.7
27	26.6
28	26.5
29	26.4
30	26.3
31	26.2
32	26.1
33	26.0
34	25.9
35	25.8
36	25.7
37	25.6
38	25.5
39	25.5
40	25.4
41	25.3
42	25.3
43	25.2
44	25.2
45	25.1
46	25.1
47	25.1
48	25.0
49	25.0
50	25.0
51	25.0
52	24.9
53	24.9
54	24.9
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57	24.9
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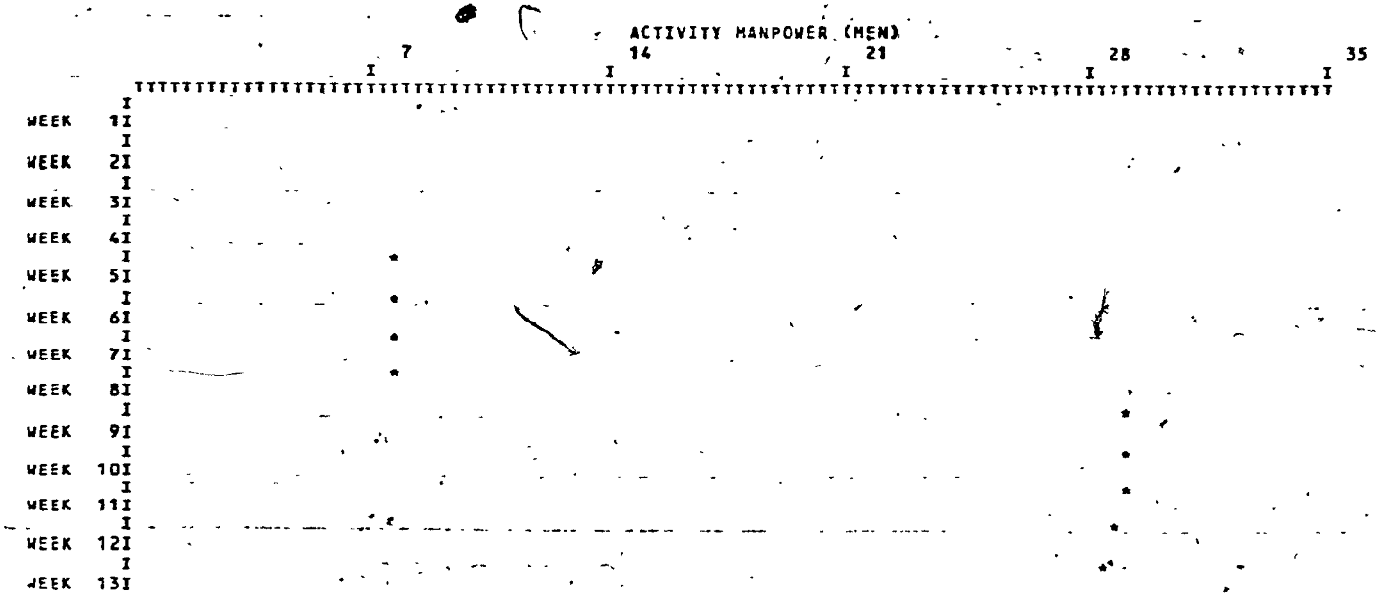
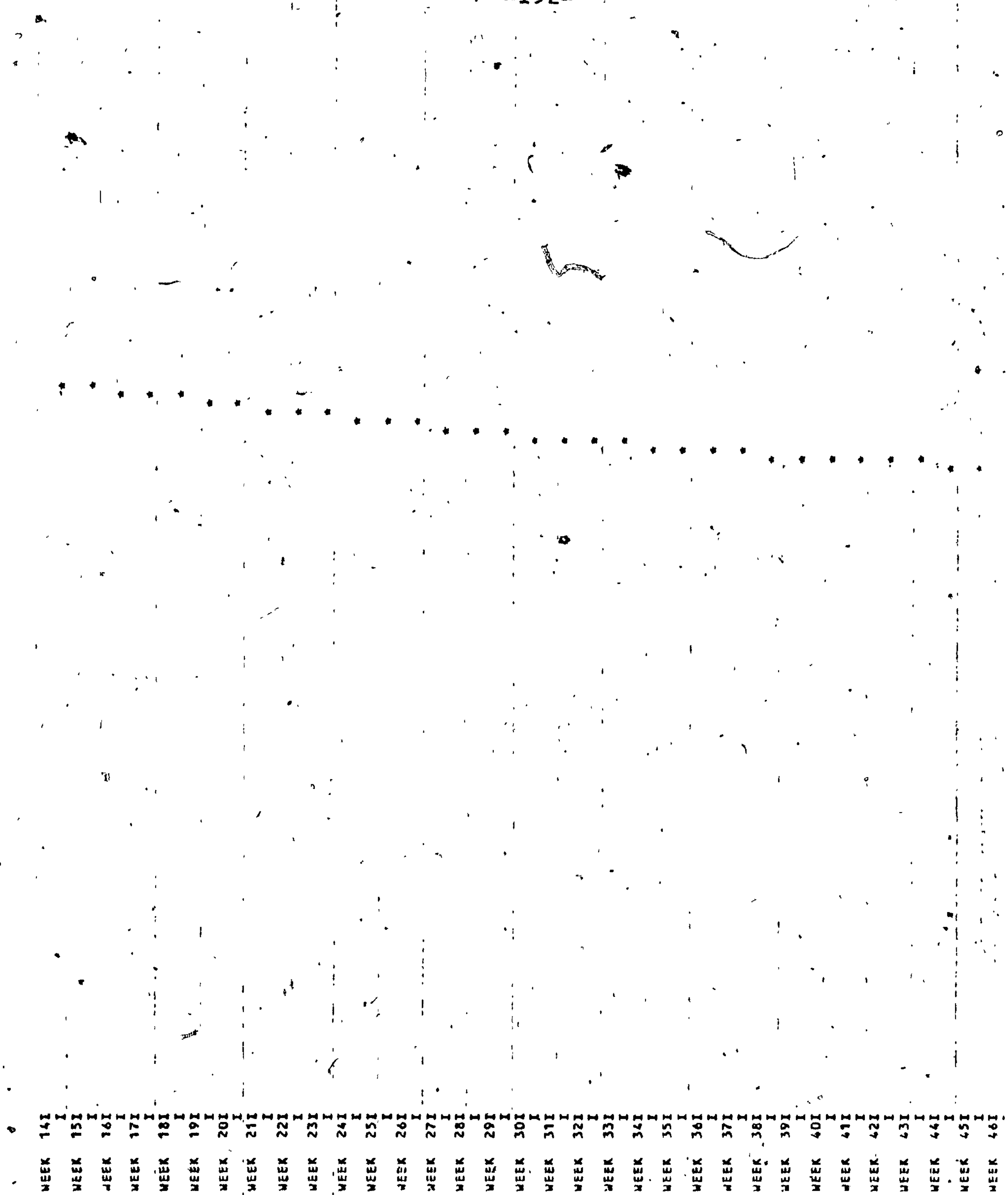
59	24.9
60	24.9
61	24.9
62	24.9
63	24.9
64	24.9
65	24.9
66	24.9
67	25.0
68	25.0
69	25.0
70	25.1
71	25.1

73	25.2
74	25.2
75	25.3
76	25.3
77	25.4
78	25.4
79	25.5
80	25.6
81	25.6
82	25.7
83	25.8
84	25.9
85	26.0
86	26.1
87	26.2
88	26.2
89	26.4
90	26.5
91	26.6
92	26.7
93	26.8
94	26.9
95	27.0
96	27.2
97	27.3
98	27.4
99	27.6
100	27.7
101	27.8
102	20.7
103	12.2
104	12.3
105	12.3

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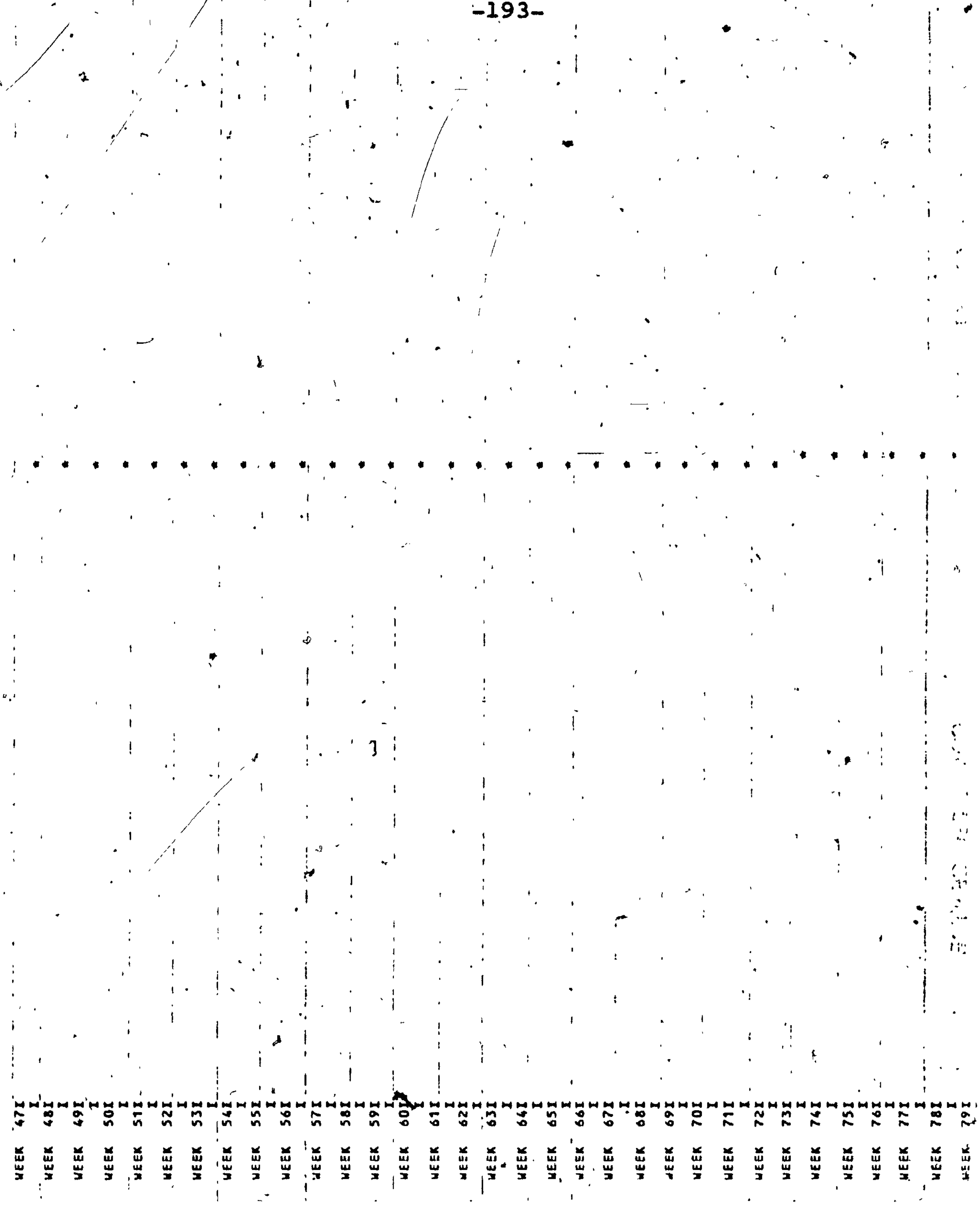
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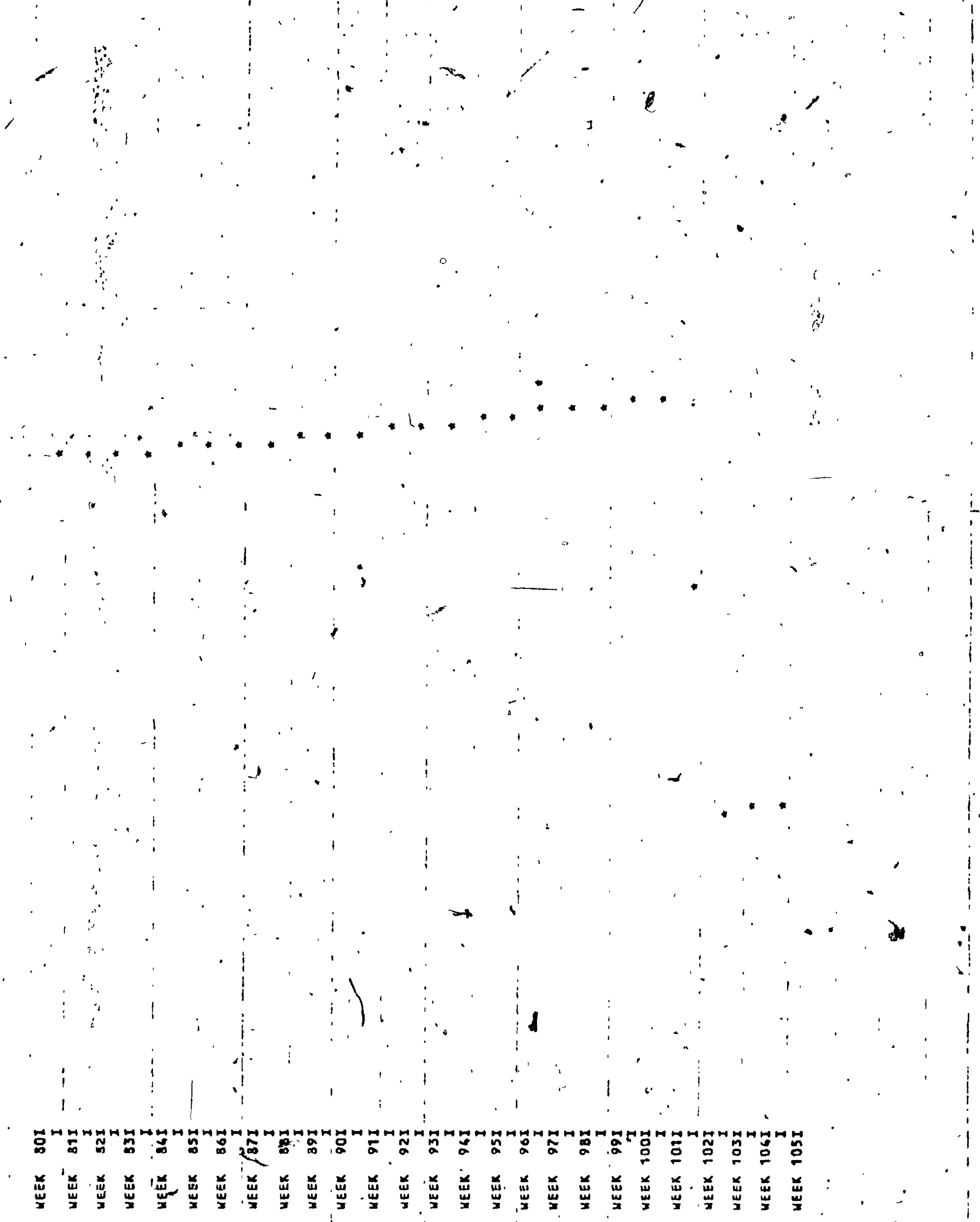
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6-2 DIVERSION TUNNEL HYDROELECTRIC PROJECT: EXAMPLE 2

Again a hydroelectric project is considered. However in this example only a very preliminary analysis is being done so that the degree of project breakeven is minimal. The activities themselves are being analysed. This example demonstrates how the Micro Model can be used to assess the merits of differenct strategies (methods) of carrying out an activity.

The total project is composed of five very encompassing activities -

1) Establishment of site facilities and infrastructure.
2) Construction of diversion tunnel.
3) Construction of mass concrete dam.
4) Building powerhouse and related facilities.
5) Construction of transmission lines and switchyard.

As can be seen the project breakdown is rather crude. Nevertheless sufficient information is available from past projects to be able to assign values, albeit rather crude measurements, to each of the listed activities. This degree of project breakdown is sufficient for preliminary analysis purposes.

The project network is as shown in FIG. 6-2. Activity 2 can be seen to be critical to the project as activities 3 and 4 cannot commence until activity 2 has been completed. It is activity 2 to which program 2 of the Micro Model will be applied.

Construction of the diversion tunnel is to be performed

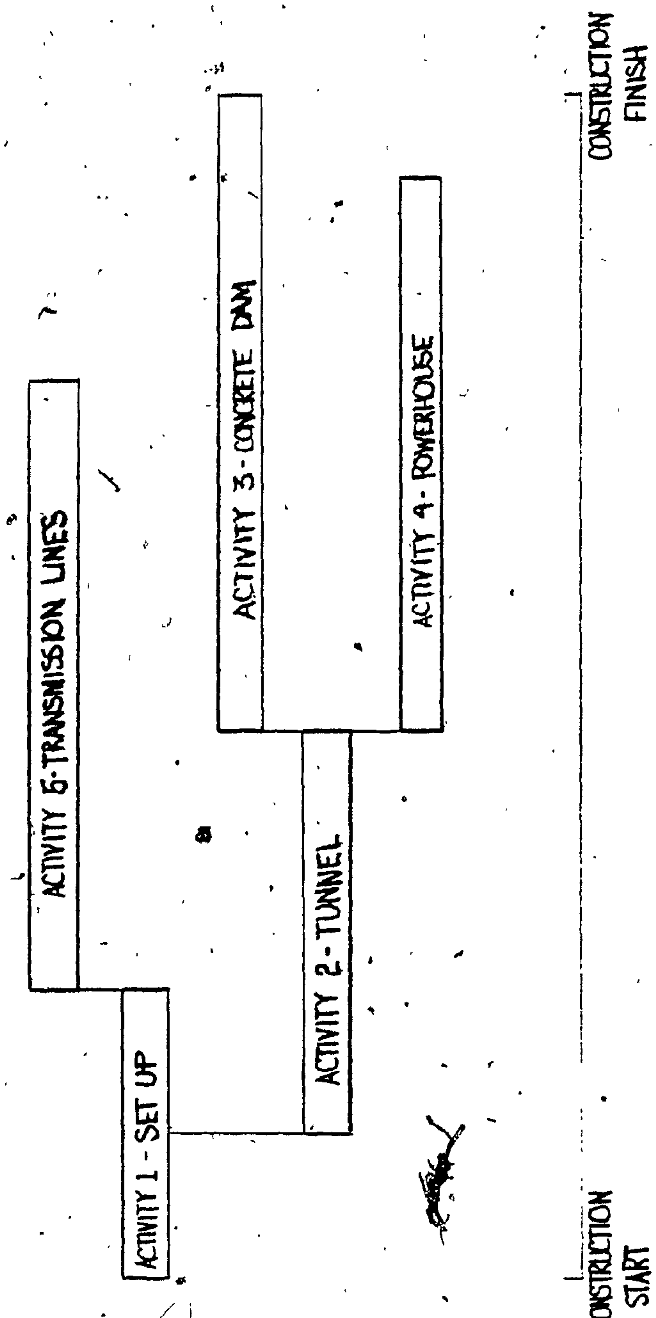

FIG. 6-2
EXAMPLE 2
PROJECT LEVEL NETWORK

using a tunneling machine. The tunnel can be worked from either one or two faces. A tunneling machine has a cost of $5,000,000 and a life expectancy of 10,000 working hours. Work exists for the machine on other projects than the one being analyzed. The equipment capital cost divided by life expectancy gives a charge of $500.00 per hour of operation. Thus for a typical 5 day 8 hour shift equipment weekly rental rate is $20,000.00. Typical shift operation of a tunneling machine results in an annual $2,000,000 maintenance and operating cost or a weekly rate of $40,000.00 per typical shift work week.

Total rock quantity to be excavated is estimated to be 240,000 cubic yards.

Standard labor wage rate for regular hours including all benefits is estimated as $20.00/man-hour. Up to two hours of overtime may be worked on a regular work day while weekend work is all overtime. Overtime wage rates are double regular rates. A maximum of two working shifts are permitted per day as time must be allowed for maintenance requirements. Shift work outside of regular work hours includes an additional 20% premium to regular wage rates. Work space available is confined so that maximum manpower at any one face cannot exceed 75 men during a shift.

CASE 1

Tunneling is performed from one face only using one 8 hour shift five days per week. Case specifics follow -

Duration	- 128 weeks
Work Quantity	- 240,000c.y.

Equipment Cost - $20,000/week

M&O Cost - $40,000/week

Mobilization Cost - $10,000

Productivity

TIME SPAN	PRODUCTIVITY
Week 1-32	0.8 cy/man-hour
33-64	0.83
64-96	0.85
97-128	0.82

Placement

% DURATION	% PLACED
20	15
40	37
60	62
80	85
100	100

CASE 2

Tunneling is again performed from one face only this time using a 10 hour shift five days a week. Continuous use of a 10 hour shift will result in a productivity rate decline.

Duration - 108 weeks

Work Quantity - 240,000 cy

Equipment Cost - $20,000/week

M&O Cost - $50,000/week

Mobilization Cost - $10,000

Productivity

TIME SPAN	PRODUCTIVITY
Week 1-27	0.73 cy/man-hour
28-54	0.75
55-81	0.77
82-108	0.76

Placement

% DURATION	% PLACED
20	15
40	36
60	61
80	84
100	100

CASE 3

Tunneling is performed from one face using two 8 hour shifts per day five days per week. Since work is carried out underground there is only a slight drop in productivity during the second shift.

	SHIFT 1	SHIFT 2
Duration	60 weeks	60 weeks
Work Quantity	120,000 cy	120,000 cy
Equipment Cost	$20,000/week	$20,000/week
M&O Cost	$40,000/week	$40,000/week
Mobilization Cost	$10,000	
Productivity		
TIME SPAN	PRODUCTIVITY	PRODUCTIVITY
Week 1-15	0.8 cy/man-hr.	0.795 cy/man-hr.
16-30	0.825	0.82
31-45	0.84	0.835
46-60	0.82	0.815
Placement		
% DURATION	% PLACED	% PLACED
20	16	16
40	37	37
60	63	63
80	85	85
100	100	100

CASE 4

One tunnel face using two 10 hour shifts five days a week.

	SHIFT 1	SHIFT 2
Duration	52 weeks	52 weeks
Work Quantity	120,000 cy	120,000 cy
Equipment Cost	$25,000/week	$25,000/week
M&O Cost	$50,000/week	$50,000/week
Mobilization Cost	$10,000	
Productivity		
TIME SPAN	PRODUCTIVITY	PRODUCTIVITY
Week 1-13	0.73	0.725
14-26	0.745	0.74
27-39	0.765	0.76
40-52	0.75	0.75
Placement		
% DURATION	% PLACED	% PLACED
20	15	15
40	36	36
60	61	61
80	84	84
100	100	100

CASE 5

Tunneling is performed at two faces. At each face one crew is used working 8 hours a day 5 days a week.

	TUNNEL FACE 1	TUNNEL FACE 2
Duration	60 weeks	60 weeks
Work Quantity	120,000cy	120,000cy
Equipment Cost	$20,000/week	$20,000/week
M&O Cost	$40,000/week	$40,000/week
Mobilization Cost	$10,000	$10,000
Productivity		
TIME SPAN	PRODUCTIVITY	PRODUCTIVITY
Week 1-15	0.81(cy/man-hr)	0.81(cy/man-hr)
16-30	0.835	0.835
31-45	0.855	0.855
46-60	0.84	0.84
Placement		
% DURATION	% PLACED	% PLACED
20	15	15
40	37	37
60	62	62
80	85	85
100	100	100

CASE 6

Two tunnel faces, each face using one 10 hour shift 5 days a week.

	TUNNEL FACE 1	TUNNEL FACE 2
Duration	52 weeks	52 weeks
Work Quantity	120,000cy	120,000cy
Equipment Cost	$25,000/week	$25,000/week
M&O Cost	$50,000/week	$50,000/week
Mobilization Cost	$10,000	$10,000
Productivity		
TIME SPAN	PRODUCTIVITY	PRODUCTIVITY
Week 1-13	0.735(cy/man-hr)	0.735(cy/man-hr)
14-26	0.755	0.755
27-39	0.78	0.78
40.52	0.77	0.77
Placement		
% DURATION	% PLACED	% PLACED
20	15	15
40	36	36
60	61	61
80	84	84
100	100	100

CASE 7

Two tunnel faces are worked on. At each face two eight hour shifts are used 5 days a week.

	TUNNEL FACE 1 SHIFT 1	TUNNEL FACE 1 SHIFT 2
Duration	30 weeks	30 weeks
Work Quantity	60,000cy	60,000cy
Equipment Cost	$20,000/week	$20,000/week
M&O Cost	$40,000/week	$40,000/week
Mobilization Cost	$10,000	
Productivity		
TIME SPAN	PRODUCTIVITY	PRODUCTIVITY
Week 1-8	0.8(cy/man-hr)	0.795(cy/man-hr)
9-16	0.825	0.82
17-24	0.84	0.835
25-30	0.82	0.815
Placement		
% DURATION	% PLACED	% PLACED
20	16	16
40	37	37
60	63	63
80	85	85
100	100	100

	TUNNEL FACE 2 SHIFT 1	TUNNEL FACE 2 SHIFT 2
Duration	30 weeks	30 weeks
Work Quantity	60,000cy	60,000cy
Equipment Cost	$20,000/week	$20,000/week
M&O Cost	$40,000/week	$40,000/week
Mobilization Cost	$10,000	
Productivity		
TIME SPAN	PRODUCTIVITY	PRODUCTIVITY
Week 1-8	0.8(cy/man-hr)	0.795(cy/man-hr)
9-16	0.825	0.82
17-24	0.84	0.835
25-30	0.82	0.815
Placement		
% DURATION	% PLACED	% PLACED
20	16	16
40	37	37
60	63	63
80	85	85
100	100	100

Results

A summary of the model outputs for each of the runs is as follows -

	FACES WORKED	NO. OF SHIFTS	OVERTIME HR/SHIFT	DUR. WEEKS	MAX.NO.OF MEN/SHIFT	MAX.WKLY CASH FLOW	CONSTANT $ ESTIMATE	$/CY	CY/$
Case 1	1	1	0	128	68	$114,249	$13,484,490	56.19	0.0178
Case 2	1	1	2	108	70	$159,224	$15,755,360	65.65	0.0152
Case 3	1	2	0	60	72	$247,889	$13,651,720	56.88	0.0176
Case 4	1	2	2	52	73	$344,495	$16,308,080	67.95	0.0147
Case 5	2	1	0	60	72	$235,174	$12,964,180	54.02	0.0185
Case 6	2	1	2	52	72	$323,273	$15,398,350	64.16	0.0156
Case 7	2	2	0	30	72	$496,274	$13,680,490	57.00	0.0175

The cases considered were by no means exhaustive of the available methods of performing the work. Suppose a decision is reached to keep the duration of activity 2 in the 50-60 week range. From a duration point of view cases 3 through 6 are viable. Project financial constraints impose a maximum limit of $250,000 on activity weekly cash flow. These restrictions leave only cases 3 and 5 viable out of the seven cases considered. The choice would most likely be made to go with the lower cost alternative which has each of the 2 faces being worked by one 8 hour shift 5 days a week (case 5).

6-3 SENSITIVITY ANALYSIS:EXAMPLE 3

In example 2 the best method of performing the tunnel work under the given constraints, was case 5. This example uses program 2 of the Micro Model to test the sensitivity of the model output of case 5 of example two for various random productivity profiles. The changes in productivity selected have no basis other than to provide a means of testing how productivity variations affect model output.

The following five productivity profile data are entered into program 2 of the Micro Model with all other inputs remaining as in example 2 -

TIME SPAN	AVERAGE PRODUCTIVITY OVER TIME SPAN (cy/man-hr.)				
	CASE 5A	CASE 5B	CASE 5C	CASE 5D	CASE 5E
Week 1-15	0.81	0.81	0.81	0.81	0.85
16-30	0.81	0.825	0.85	0.88	0.85
31-45	0.81	0.825	0.85	0.88	0.85
46-60	0.81	0.81	0.81	0.81	0.85

Results

A summary of the model outputs for each of the selected productivity profiles is as follows -

	MAX. NO. OF MEN/SHIFT	MAX. WEEKLY CASH FLOW	CONSTANT $ ESTIMATE	$/CY
Case 5A	75	$240,506	$13,150,870	$54.80
Case 5B	74	238,047	13,086,710	54.53
Case 5C	71	234,164	12,985,110	54.10
Case 5D	69	229,829	12,871,370	53.63
Case 5E	72	234,793	12,871,770	53.63

This example keeps activity duration constant while labour resource requirements vary. In comparing cases 5A and 5D, which have a 5% difference in productivity rate magnitude, cost per cubic yard percentage difference is 2% while change in required man-hours is a 5% difference. Results show that changes in productivity affect activity performance measures and activity resource requirements.

6-4 SENSITIVITY ANALYSIS:EXAMPLE 4

This example uses program 1 of the Micro Model as a sensitivity tool. Case 1 of example 2 will be used as the base case with a further restriction that manpower must remain constant at 60 throughout the activity. Productivity profile points are selected at random to observe the effects on activity duration.

The following five productivity profiles points were selected. Values used represent changes in both productivity magnitudes and profile shapes.

PERCENTAGE SPAN OF ACTIVITY	AVERAGE PRODUCTIVITY OVER TIME SPAN (cy/man-hr.)				
	CASE 1A	CASE 1B	CASE 1C	CASE 1D	CASE 1E
0-25%	0.80	0.75	0.75	0.90	0.83
25-50	0.83	0.83	0.75	0.90	0.87
50-75	0.85	0.90	0.75	0.90	0.90
75-100	0.82	0.84	0.75	0.90	0.87

Results

Activity durations under the various productivity rate scenarios were as follows:

	ACTIVITY DURATION
Case 1A	129.8 weeks
Case 1B	149.5
Case 1C	134.5
Case 1D	112.2
Case 1E	126.4

The results show that productivity can have a profound influence on activity duration, all other inputs being constant. As example, there is a 18% difference in productivity rate magnitude between cases 1C and 1D which produces a 20% difference in activity duration. These results indicate that substantial savings in activity duration can be realized if methods can be found to improve productivity.

6-5 SUMMARY

The four examples presented in this chapter are representative of some of the possible uses of the Micro Model, its versatility and generic concepts.

Example 2 is particularily indicative of the type of decisions that must be made during conceptual planning stages of a project. Once the methods are selected a more detailed and extensive analysis can be performed as presented in example 1.

The Micro Model is a tool aiding in the identification of the impact of activity level decision making for financial planning purposes.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7-1 CONCLUSIONS

The financial planning models developed aid investigation into the impacts of controllable and uncontrollable factors upon project financial performance. These models are designed to be used early in the project life-cycle to determine project financial feasibility and thus minimize risk to allocated funds.

The Macro Models

Sensitivity testing of uncontrollable factors and of the engineering decision variables of planning, scheduling, procurement and contract strategies to the client's performance measures of net present value and total cost ("bricks and mortar" + escalation + financing), and vice versa, are provided by the Macro Models. To aid in capital expenditure modeling the versatile beta distribution is introduced to model project cash flow during construction.

The selected project level performance measures were observed to be relatively insensitive to the profile shape of the construction cash flow. This property allows simple "rules of thumb" to be employed for construction cash flow when determining total cost and net present value.

Escalation and finance costs become significant, and were shown to substantially exceed project "bricks and mortar" cost, on long duration projects subject to significant escalation. This, in conjunction with irrelevance of cash flow shape, indicates that uncontrollable factors such as loan requirements, escalation rate projections, interest rates and market prices have substantially more impact upon project financial planning than do engineering decision variables at the project level.

Project level performance measures were observed to be sensitive to construction duration. The breakeven concept introduced indicates the possibility of construction duration crashing without incurring any change in the values of project performance measures.

The Micro Model

The Micro Model is the first step towards a means of accounting for variable productivity rates and the effects of construction resources in preconstruction financial planning. The model allows investigation into how activity level decision variables (resources) affect the performance measures of activity constant dollar cost and activity duration and can be effective in establishing optimum methods of construction.

Chapter 5 covers the generic concepts of activity description. The greatest hindrance to the model is the lack of conclusive research in the area of definition of variation in construction productivity. However, as developed, the model is capable of reflecting future productivity research results through the substitution of better productivity functions.

7-2 RECOMMENDATIONS FOR FUTURE WORK

The Macro Models

Future work could be directed at adding greater realism to the Macro Models although at the cost of greater complexity. Super-imposition of beta distributions could be used to model multi-modality of construction cash flows. More accurate escalation functions can be introduced into the models when forecasts are sufficiently accurate enough to do so. In addition a better correlation may be found to exist between escalation rates and interest rates. Financing terms and agreements may be more complex than those assumed by the models. The NPV Macro Models can be expanded to include non-uniform revenue and expenditure functions. The possibilities for more realism are virtually limitless; however, more time and effort spent on more accurate modeling will not necessarily return more accurate results. Model results can be no better than data input and financial planning of large projects requires forecasting well into the unknown future.

The Micro Model

As presented, the computer program for the Micro Model (Appendix B) consists of separate programs. Operation duration is established by specifying operation labor profile and productivity on a normalized time basis in the first program. These results are employed by the second program to calculate operation total cost and activity duration, activity labor profile, activity cash flow and activity cost in terms of constant dollars.

Future steps in model programming should include incorporation of the two present programs into one more versatile program. Further development is required to allow the results of the activity level analysis to be placed directly into the project level. To carry out such improvements requires the establishment of an effective data base structure. The data base would facilitate analysis by allowing changes to be made to the inputs required for operation and activity description without having to re-input unchanged data. This data storage would also allow file storage to be used for consultation purposes at later phases of the project life-cycle.

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APPENDIX A

MACRO MODEL PROGRAMS

The Macro Model computer programs are listed in this appendix. Programming language is standard Fortran. The four Macro Model programs are;

1) total cost,
2) breakeven curve: total cost criteria,
3) net present value and
4) breakeven value: NPV criteria.

A-1 TOTAL COST PROGRAM

This program calculates project total cost and its components; escalation and financing costs. The constant dollar capital cost is entered along with the appropriate beta parameters describing the cash flow profile shape. Escalation is represented by a linear function. An escalation rate is assigned to the project construction start date. The slope of the escalation function is defined by entering a yearly rate of escalation change. Likewise, interest rate is linearly represented. Interest rate is given by summing the escalation rate and a defined constant real rate of return. The final required input is that of the owner equity percentage.

Output lists variables input values along with capital expenditure, escalation cost, financing cost and total project cost.

```
C        TOTAL COST MANAGEMENT AND PRODUCTIVITY PROGRAM
C
C          THIS PROGRAM CALCULATES THE TOTAL PROJECT COST
C        FOR A NUMBER OF ALTERNATIVES ALLOWING A SENSITIVITY
C        ANALYSIS
C
C          ESCALATION DURING THE CONSTRUCTION PHASE IS GIVEN
C        BY A PROJECT START ESCALATION RATE AND A YEARLY RATE
C        OF INCREASE
C
C          INTEREST DURING CONSTRUCTION IS GIVEN BY THE RATE OF
C        INFLATION PLUS A CONSTANT REAL RATE OF RETURN
C        BORROWED FUNDS PLUS INTEREST ARE NOT DUE UNTIL THE END
C        OF THE CONSTRUCTION DURATION
C
C          THE PROJECT CASH FLOW IS MODELED BY THE BETA FUNCTION
C        WHICH IS DEFINED BY PARAMETERS P AND Q
C
C
C
C                    VARIABLE LIST
C         CC-PROJECT CAPITAL COST IN CONSTANT DOLLARS
C        P,Q-BETA PARAMETERS
C          T-CONSTRUCTION DURATION IN YEARS
C          E-RATE OF ESCALATION AT PROJECT START
C         DE-YEARLY RATE OF ESCALATION INCREASE
C          R-CONSTANT INTEREST LEAD OVER INFLATION
C          F-EQUITY INPUT PERCENTAGE
C
      DIMENSION ET(20,20),FT1(20,20)
C
C
C        VARIABLES P&Q DESCRIBE BETA DISTRIBUTION,T THE PROJECT
C        DURATION,E THE ESCALATION RATE,R LEAD FACTOR FOR INTERES
C        AND F THE EQUITY INPUT AND DE THE RATE OF INCREASE OF
C        ESCALATION
C
      WRITE(1,10)
   10 FORMAT(1X,/,1X,'     ***** TOTAL COST *****',/,1X,
     ^'ENTER NUMBER OF CASES TO BE CONSIDERED')
      READ(1,*)N
C
      DO 12 IJK=1,N
C
      WRITE(1,498)
  498 FORMAT(1X,'ENTER CONSTRUCTION COST')
      READ(1,*)CC
C
      WRITE(1,500)
  500 FORMAT(1X,'ENTER PARAMETER VALUES FOR BETA DISTRIBUTION',/
     ^1X,3X,'P=')
      READ(1,*)P
      WRITE(1,502)
  502 FORMAT(1X,3X,'Q=')
      READ(1,*)Q
C
      WRITE(1,504)
```

```
  504 FORMAT(1X,'ENTER THE CONSTRUCTION DURATION IN YEARS')
      READ(1,*)T
C
      WRITE(1,506)
  506 FORMAT(1X,'ENTER THE BASE ESCALATION RATE ')
      READ(1,*)E
      E=E/100.0
C
      WRITE(1,507)
  507 FORMAT(1X,'ENTER RATE OF ESCALATION INCREASE')
      READ(1,*)DE
      DE=DE/100.0
C
      WRITE(1,508)
  508 FORMAT(1X,'ENTER THE INTEREST LEAD FACTOR OVER',/,
     ^1X,'ESCALATION')
      READ(1,*)R
      R=R/100.0
C
      WRITE(1,510)
  510 FORMAT(1X,'ENTER THE EQUITY INPUT')
      READ(1,*)F
      F=F/100.0
C
C
C       WRITE DESCRIPTION OF PROGRAM
C
      DEP=DE*100.0
      EP=E*100
      FP=F*100
      RP=R*100
      RRP=EP+RP
      WRITE(2,84)T,FP,EP,DEP,RRP
   84 FORMAT(/,3X,'THE FOLLOWING ARE THE COSTS INCURRED FOR',/,
     ^2X,'A PROJECT OF DURATION ',F5.2,' YEARS.THE OWNERS',/,
     ^2X,'EQUITY INPUT IS ',F5.2,' %.THE PROJECT OCCURS',/,
     ^2X,'UNDER AN ESCALATION RATE OF ',F5.2,' % WHICH',/,
     ^2X,'INCREASES AT A YEARLY RATE OF ',F5.2,' % AND A',/,
     ^2X,'START INTEREST RATE OF ',F5.2,' % WHICH INCREASES',/,
     ^2X,'AT THE SAME YEARLY RATE AS ESCALATION')
C
C     CALCULATION OF 1/B EQUALS B1 FOR BETA DISTRIBUTION
C
      QP=Q-P
      CALL GMMA(P,PG,PE)
      CALL GMMA(Q,QG,QE)
      CALL GMMA(QP,QPG,QPE)
      B1=QG/(PG*QPG)
      WRITE(2,85)P,Q,B1
   85 FORMAT(2X,'THE CASH FLOW PROFILE IS GIVEN BY P=',F5.2,
     ^' AND Q=',F5.2,' THE VALUE B1=',F8.3)
C
C       TOTAL CUMULATIVE CONSTANT DOLLAR EXPENDITURE=CC
C
      WRITE(2,83)CC
   83 FORMAT(1X,10X,'THE TOTAL CAPITAL EXPENDITURE=$',F15.2)
C
```

```
C
C                 CALCULATE THE ESCALATION COST ET
C        ROMBERG INTEGRATION; 'NUMERICAL METHODS',R.W. HORNBECK,
C                    QUANTUM PUBLISHERS,1975
C
C
      EE1=0.0001
      ET(1,1)=0.0
      TPP=P-1.0
      IF(TPP.EQ.0)ET(1,1)=(T/2)*((B1*T**(QP-1))/(T**(Q-1)))
      TQPP=QP-1.0
      IF(TQPP.EQ.0)ET(1,1)=(T/2)*((B1*T**(P-1)*EXP(E*T+0.5*DE*T*
     ^/(T**(Q-1)))
      IF(TPP.EQ.0.AND.TQPP.EQ.0)ET(1,1)=(T/2)*
     ^((B1)/(T**(Q-1))+(B1*EXP(E*T+0.5*DE*T**2))/(T**(Q-1)))
      TT=T/2.0
      ET(1,2)=(ET(1,1)/2)+(T/2)*((B1*TT**(P-1)*(T-TT)**(QP-1)
     ^*EXP(E*TT+0.5*DE*TT**2))/(T**(Q-1)))
      ET(2,1)=(1/3)*(4*ET(1,2)-ET(1,1))
      J1=3
  102 CONTINUE
      DX1=T/2**(J1-1)
      X1=-1*DX1
      N1=2**(J1-2)
      SUM1=0.0
      I1=1
  105 CONTINUE
      X1=X1+2*DX1
      SUM1=SUM1+(B1*EXP(E*X1+0.5*DE*X1**2)*X1**(P-1)*
     ^(T-X1)**(QP-1))/(T**(Q-1))
      IF(I1.EQ.N1)GO TO 110
      I1=I1+1
      GO TO 105
  110 CONTINUE
      JJ1=J1-1
      ET(1,J1)=ET(1,JJ1)/2+(DX1*SUM1)
      L1=2
  115 CONTINUE
      K1=J1+1-L1
      L11=L1-1
      K11=K1+1
      ET(L1,K1)=(4**L11*ET(L11,K11)-ET(L11,K1))/(4**L11-1)
      IF(L1.EQ.J1)GO TO 120
      L1=L1+1
      GO TO 115
  120 CONTINUE
      Z1=ABS((ET(J1,1)-ET(JJ1,1))/ET(J1,1))
      IF(Z1.LT.EE1)GO TO 125
      IF(J1.EQ.20)GO TO 135
      J1=J1+1
      GO TO 102
  125 CONTINUE
      ETT=ET(J1,1)-1.0
      ETT=ETT*CC
      WRITE(2,130)ETT
  130 FORMAT(1X,10X,'THE ESCALATION COST              =$',F15.2)
      GO TO 145
```

```
  135 CONTINUE
      ETT=ET(20,1)-1.0
      WRITE(2,140)ETT
  140 FORMAT(1X,5X,'RESTRICTED ESCALATION COST IS $',F10.5)
  145 CONTINUE
C
C                    CALCULATION OF FINANCING COST
C         ROMBERG INTEGRATION;"NUMERICAL METHODS",R.W. HORNBECK,
C                    QUANTUM PUBLISHERS,1975
C
      RR=E+R
      RCON=RR*T+0.5*DE*T**2
      EE2=0.0001
      FT1(1,1)=0.0
      TPF=P-1.0
      IF(TPF.EQ.0) FT1(1,1)=(T/2)*((B1*T**(QP-1)*EXP(RCON))/
     ^(T**(Q-1)))
      TQPF=QP-1.0
      IF(TQPF.EQ.0) FT1(1,1)=(T/2)*((B1*T**(P-1)*
     ^EXP(E*T+0.5*DE*T**2))/(T**(Q-1)))
      IF(TPF.EQ.0.AND.TQPF.EQ.0) FT1(1,1)=(T/2)*
     ^((B1*T*(QP-1)*EXP(RCON))/(T**(Q-1))+
     ^(B1*T**(P-1)*EXP(E*T+0.5*DE*T**2))/(T**(Q-1)))
      TT=T/2.0
      FT1(1,2)=(FT1(1,1)/2)+(T/2)*((B1*TT**(P-1)*(T-TT)
     ^**(QP-1)*EXP(E*TT+0.5*DE*TT**2)*
     ^EXP(RCON-RR*TT-0.5*DE*TT**2))/(T**(Q-1)))
      FT1(2,1)=(1/3)*(4*FT1(1,2)-FT1(1,1))
      J2=3
  202 CONTINUE
      DX2=T/2**(J2-1)
      X2=-1.0*DX2
      N2=2**(J2-2)
      SUM2=0.0
      I2=1
  205 CONTINUE
      X2=X2+2*DX2
      SUM2=SUM2+(B1*EXP(RCON-RR*X2-0.5*DE*X2**2)*
     ^EXP(E*X2+0.5*DE*X2**2)*X2**(P-1)
     ^*(T-X2)**(QP-1))/(T**(Q-1))
      IF(I2.EQ.N2)GO TO 210
      I2=I2+1
      GO TO 205
  210 CONTINUE
      JJ2=J2-1
      FT1(1,J2)=FT1(1,JJ2)/2+(DX2*SUM2)
      L2=2
  215 CONTINUE
      K2=J2+1-L2
      L12=L2-1
      K12=K2+1
      FT1(L2,K2)=(4**L12*FT1(L12,K12)-FT1(L12,K2))/
     ^(4**L12-1)
      IF(L2.EQ.J2)GO TO 220
      L2=L2+1
      GO TO 215
  220 CONTINUE
```

```
      Z2=ABS((FT1(J2,1)-FT1(JJ2,1))/FT1(J2,1))
      IF(Z2.LT.EE2)GO TO 225
      IF(J2.EQ.20)GO TO 235
      J2=J2+1
      GO TO 202
  225 CONTINUE
      FTA=FT1(J2,1)
      GO TO 245
  235 CONTINUE
      WRITE(2,240)
  240 FORMAT(1X,5X,'REQUIRED ACCURACY FOR FT1 NOT OBTAINED')
  245 CONTINUE
      FT=(1-F)*(FTA*CC-ETT-CC)
      WRITE(2,350)FT
  350 FORMAT(1X,10X,'THE FINANCING COST          =$',F15.2)
      TC=CC+ETT+FT
      WRITE(2,360)TC
  360 FORMAT(1X,10X,'THE TOTAL PROJECT COST      =$',F15.2)
   12 CONTINUE
      STOP
      END

D  R04-00     MAINPROG    .MAIN     26/11/82. 16:24:28  TABLE SPAC
FER:   20 LINES/1321 BYTES    STACK SPACE: 197 WORDS
ION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
: LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002          **
   C
   C                 SUBROUTINE TO CALCULATE GAMMA FUNCTION
   C         BY. C.HASTINGS;'APPROXIMATIONS FOR DIGITAL COMPUTERS',
   C                 PRINCETON UNIVERSITY,1955
   C
         SUBROUTINE GMMA(XX,GX,IER)
         IF(XX-57.)20,20,25
      25 IER=2
         GX=1.E75
         RETURN
      20 X=XX
         ERR=1.0E-6
         IER=0
         GX=1.0
         IF(X-2.0)30,30,35
      40 IF(X-2.0)45,45,35
      35 X=X-1.0
         GX=GX*X
         GO TO 40
      30 IF(X-1.0)50,55,45
   C
   C       SEE IF X IS NEAR NEGATIVE INTEGER OR ZERO
   C
      50 IF(X-ERR)60,60,65
      60 Y=FLOAT(INT(X))-X
         IF(ABS(Y)-ERR)70,70,75
      75 IF(1.0-Y-ERR)70,70,80
   C
   C       X NOT NEAR A NEGATIVE INTEGER OR ZERO
   C
      80 IF(X-1.0)65,65,45
      65 GX=GX/X
         X=X+1.0
         GO TO 80
      45 Y=X-1.0
         GY=1.0+Y*(-0.5771017+Y*(0.9858540+Y*(-0.8764218
        ^+Y*(0.8328212+Y*(-0.5684729+Y*(0.2548205
        ^+Y*(-0.05149930)))))))
         GX=GX*GY
      55 RETURN
      70 IER=1
         RETURN
         END

7D  R04-00     SUBROUTINE  GMMA      26/11/82  16:24:29  TABLE SPAC
FFER:   20 LINES/1321 BYTES    STACK SPACE: 297 WORDS
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

A-2 BREAKEVEN CURVE PROGRAM: TOTAL COST

The variable input requirements are as listed for the total cost program. The entered construction duration is divided into ten points of equal spacing. For each point a breakeven value is calculated and output. The ten calculated values define the breakeven curve.

```
C
C        BREAKEVEN CURVE PROGRAM
C
C        PROGRAM STORED AS BEVENEI.FTN
C
C            PROGRAM CALCULATES THE VALUES OF THE CONSTANT
C          DOLLAR CAPITAL EXPENDITURES THAT CAN BE INCURRED
C          WHEN THE CONSTRUCTION DURATION IS REDUCED BELOW
C          ITS INITIAL ESTIMATE.
C
C              PROJECT CASH FLOW IN TERMS OF CONSTANT DOLLARS
C          IS MODELED BY THE BETA FUNCTION WHICH IS DEFINED BY
C          THE PARAMETERS P AND Q
C
C              INFLATION PROFILE IS GIVEN BY A RATE AT THE PROJEC
C          START PLUS A YEARLY RATE OF INCREASE
C
C              INTEREST RATE IS GIVEN BY A CONSTANT FIXED REAL RA
C          PLUS THE RATE OF INFLATION.
C
C
C                        VARIABLE LIST
C          CC-TOTAL PROJECT CAPITAL ESTIMATE
C         P,Q-BETA PARAMETERS
C           T-CONSTRUCTION DURATION IN YEARS
C           E-RATE OF INFLATION AT THE PROJECT START
C          DE-RATE OF INCREASE OF INFLATION
C           R-INTEREST RATE LEAD OVER INFLATION
C           F-EQUITY INPUT PERCENTAGE
C
      DIMENSION TC(10)
C
      WRITE(1,899)
  899 FORMAT(1X,/,1X,'*****BREAKEVEN CURVE TOTAL COST BASIS*****
      WRITE(1,897)
  897 FORMAT(1X,'ENTER CONSTRUCTION COST')
      READ(1,*)CC
C
      WRITE(1,900)
  900 FORMAT(1X,'ENTER PARAMETER VALUES FOR BETA DISTRIBUTION',
     ^/,1X,3X,'P=')
      READ(1,*)P
      WRITE(1,902)
  902 FORMAT(1X,3X,'Q=')
      READ(1,*)Q
C
      WRITE(1,904)
  904 FORMAT(1X,'ENTER THE CONSTRUCTION DURATION IN YEARS')
      READ(1,*)T
C
      WRITE(1,906)
  906 FORMAT(1X,'ENTER THE ESCALATION RATE ')
      READ(1,*)E
      E=E/100.0
C
      WRITE(1,907)
  907 FORMAT(1X,'ENTER RATE OF ESCALATION INCREASE')
```

```
      READ(1,*)DE
      DE=DE/100.0
C
      WRITE(1,908)
  908 FORMAT(1X,'ENTER THE INTEREST RATE LAG FACTOR FOR',/,
     ^1X,'INTEREST OVER ESCALATION')
      READ(1,*)R
      R=R/100.0
C
      WRITE(1,910)
  910 FORMAT(1X,'ENTER THE EQUITY INPUT')
      READ(1,*)F
      F=F/100.0
C
C         CASH FLOW PARAMETER CALCULATION
C
      QP=Q-P
      CALL GMMA(P,PG,PE)
      CALL GMMA(Q,QG,QE)
      CALL GMMA(QP,QPG,QPE)
      B1=QG/(PG*QPG)
C
C         DESCRIPTION
C
      DEP=DE*100.0
      EP=E*100
      RP=R*100
      FP=F*100
      RRP=RP+EP
      WRITE(2,540)P,Q,EP,DEP,RRP,FP
  540 FORMAT(/,3X,'FOLLOWING ARE THE BREAKEVEN CURVE POINTS WHEN
     ^/,10X,'P=',F5.2,/,10X,'Q=',F5.2,/,10X,
     ^'ESCALATION=',F5.2,'%',/,10X,'ESCALATION INCREASE=',F5.2,'
     ^/,10X,'INTEREST=',F5.2,'%',/,10X,'EQUITY=',F5.2,'%')
      WRITE(2,541)
  541 FORMAT(1X,/,1X,'THE POINTS GIVEN ARE NORMALIZED',/,
     ^1X,'TO GET ACTUAL VALUES MULTIPLY',/,
     ^1X,'VALUES BY CONSTRUCTION COST')
C
C     DO LOOP DIVIDE DURATION INTO 10 DIVISIONS
C
      DO 520 IT=1,10
      TT=(IT/10.0)*T
      CALL TCPROG(P,Q,TT,B1,E,DE,R,RESA,RESB)
      TC(IT)=F*RESA+(1-F)*RESB
  520 CONTINUE
      DO 525 JT=1,10
      TOT=TC(10)/TC(JT)
      TI=(JT/10.0)*T
      WRITE(2,530)TI,TOT
  530 FORMAT(1X,'AT TIME=',F5.2,' YEARS BREAKEVEN VALUE='F10.6)
  525 CONTINUE
      WRITE(2,443)
  443 FORMAT(1X,/,/1X,'FOLLOWING ARE THE ACTUAL BREAKEVEN VALUES
      DO 531 JTT=1,10
      TOT2=(TC(10)/TC(JTT))*CC
      TI2=(JTT/10.0)*T
```

```
** LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002        **
      WRITE(2,532)TI2,TOT2
  532 FORMAT(1X,'AT TIME=',F5.2,' YEARS ACTUAL R.E. VALUE=$'F15.
  531 CONTINUE
      TCC=TC(10)*CC
      WRITE(2,810)TCC,T
  810 FORMAT(1X,'TOTAL CONSTRUCTION COST IS $',F15.2,/,
     *1X,'TOTAL CONSTRUCTION DURATION IS ',F5.2,' YEARS')
      STOP
      END

7D  R04-00     MAINPROG    ,MAIN     26/11/82  16:24:51  TABLE SPAC
FFER:   20 LINES/1321 BYTES     STACK SPACE: 167 WORDS
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
: LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002         **
C
C                       GAMMA CALCULATION
C         BY C.HASTINGS;'APPROXIMATIONS FOR DIGITAL COMPUTERS',
C                      PRINCETON UNIVERSITY,1955
C
      SUBROUTINE GMMA(XX,GX,IER)
      IF(XX-57.)6,6,4
    4 IER=2
      GX=1.E75
      RETURN
    6 X=XX
      ERR=1.0E-6
      IER=0
      GX=1.0
      IF(X-2)50,50,15
   10 IF(X-2.0)110,110,15
   15 X=X-1.0
      GX=GX*X
      GO TO 10
   50 IF(X-1)60,120,110
   60 IF(XX-ERR)62,62,80
   62 Y=FLOAT(INT(X))-X
      IF(ABS(Y)-ERR)130,130,64
   64 IF(1.0-Y-ERR)130,130,70
   70 IF(X-1)80,80,110
   80 GX=GX/X
      X=X+1
      GO TO 70
  110 Y=X-1
      GY=1.0+Y*(-0.5771017+Y*(0.9858540+Y*(-0.8764218
     ^+Y*(0.8328212+Y*(-0.5684729+Y*(0.2548205
     ^+Y*(-0.05149930)))))))
      GX=GX*GY
  120 RETURN
  130 IER=1
      RETURN
      END

7D  R04-00     SUBROUTINE  GMMA      26/11/82  16:24:52  TABLE SPAC
FFER:   20 LINES/1321 BYTES    STACK SPACE: 297 WORDS
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
C
C                CALCULATION OF TOTAL COST AT ANY TIME
C      ROMBERG INTEGRATION; 'NUMERICAL METHODS',R.W. HORNBECK
C                   QUANTUM PUBLISHERS,1975
C
      SUBROUTINE TCPROG(P,Q,TT,B1,E,DE,R,TCA,TCB)
      DIMENSION Z1(20,20),Z2(20,20)
      ER=0.0001
      Z1(1,1)=0.0
      TPP=P-1.0
      IF(TPP.EQ.0)Z1(1,1)=(TT/2)*((B1*TT**(Q-P-1))/(TT**(Q-1)))
      TQPP=Q-P-1.0
      IF(TQPP.EQ.0)Z1(1,1)=(TT/2)*((B1*TT**(P-1)
     ^*EXP(E*TT+0.5*DE*TT**2))/(TT**(Q-1)))
      IF(TPP.EQ.0.AND.TQPP.EQ.0)Z1(1,1)=(TT/2)*
     ^((B1)/(TT**(Q-1))+(B1*EXP(E*TT+0.5*DE*TT**2))
     ^/(TT**(Q-1)))
      TH=TT/2.0
      Z1(1,2)=(Z1(1,1)/2)+(TH)*((B1*TH**(P-1)*(TT-TH)**
     ^(Q-P-1)*EXP(E*TH+0.5*DE*TH**2))/(TT**(Q-1)))
      Z1(2,1)=(1/3)*(4*Z1(1,2)-Z1(1,1))
      J=3
  102 CONTINUE
      DX=TT/2**(J-1)
      X=-1.0*DX
      N=2**(J-2)
      SUM=0.0
      I=1
  105 CONTINUE
      X=X+2*DX
      SUM=SUM+(B1*EXP(E*X+0.5*DE*X**2)*X**(P-1)*
     ^(TT-X)**(Q-P-1))/(TT**(Q-1))
      IF(I.EQ.N)GO TO 110
      I=I+1
      GO TO 105
  110 CONTINUE
      JJ=J-1
      Z1(1,J)=Z1(1,JJ)/2+DX*SUM
      L=2
  115 CONTINUE
      K=J+1-L
      L1=L-1
      K1=K+1
      Z1(L,K)=(4**L1*Z1(L1,K1)-Z1(L1,K))/(4**L1-1.0)
      IF(L.EQ.J)GO TO 120
      L=L+1
      GO TO 115
  120 CONTINUE
      AB=ABS((Z1(J,1)-Z1(JJ,1))/Z1(J,1))
      IF(AB.LT.ER)GO TO 125
      IF(J.EQ.20)GO TO 135
      J=J+1
      GO TO 102
  125 CONTINUE
  135 CONTINUE
      TCA=Z1(J,1)
      RR=E+R
```

```
      RCON=RR*TT+0.5*DE*TT**2
      Z2(1,1)=0.0
      TPF=P-1.0
      IF(TPF.EQ.0)Z2(1,1)=(TT/2)*((B1*TT**(Q-P-1)*EXP(RCON))/
     ^(TT**(Q-1)))
      TQPF=Q-P-1.0
      IF(TQPF.EQ.0)Z2(1,1)=(TT/2)*((B1*TT**(P-1)*
     ^EXP(E*TT+0.5*DE*TT**2))/(TT**(Q-1)))
      IF(TPF.EQ.0.AND.TQPF.EQ.0)Z2(1,1)=(TT/2)*
     ^((B1*TT*(Q-P-1)*EXP(RCON))/(TT**(Q-1))+
     ^(B1*TT**(P-1)*EXP(E*TT+0.5*DE*TT**2))/(TT**(Q-1)))
      Z2(1,2)=(Z2(1,1)/2)+TH*((B1*TH**(P-1)*(TT-TH)
     ^**(Q-P-1)*EXP(E*TH+0.5*DE*TH**2)*
     ^EXP(RCON-RR*TH-0.5*DE*TH**2))/(TT**(Q-1)))
      Z2(2,1)=(1/3)*(4*Z2(1,2)-Z2(1,1))
      JA=3
  202 CONTINUE
      DXA=TT/2**(JA-1)
      XA=-1.0*DXA
      NA=2**(JA-2)
      SUMA=0.0
      IA=1
  205 CONTINUE
      XA=XA+2*DXA
      SUMA=SUMA+(B1*EXP(RCON-RR*XA-0.5*DE*XA**2)*
     ^EXP(E*XA+0.5*DE*XA**2)*XA**(P-1)
     ^*(TT-XA)**(Q-P-1))/(TT**(Q-1))
      IF(IA.EQ.NA)GO TO 210
      IA=IA+1
      GO TO 205
  210 CONTINUE
      JJA=JA-1
      Z2(1,JA)=Z2(1,JJA)/2+DXA*SUMA
      LA=2
  215 CONTINUE
      KA=JA+1-LA
      L1A=LA-1
      K1A=KA+1
      Z2(LA,KA)=(4**L1A*Z2(L1A,K1A)-Z2(L1A,KA))/(4**L1A-1.0)
      IF(LA.EQ.JA)GO TO 220
      LA=LA+1
      GO TO 215
  220 CONTINUE
      ABA=ABS((Z2(JA,1)-Z2(JJA,1))/Z2(JA,1))
      IF(ABA.LT.ER)GO TO 225
      IF(JA.EQ.20)GO TO 235
      JA=JA+1
      GO TO 202
  225 CONTINUE
  235 CONTINUE
      TCB=Z2(JA,1)
      RETURN
      END
```

```
70  R04-00      SUBROUTINE  TCPROG    26/11/82  16:24:58  TABLE SPAC
FFER:   20 LINES/1321 BYTES     STACK SPACE: 183 WORDS
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

A-3 NET PRESENT VALUE PROGRAM

The assumptions of linear escalation and interest rates during construction introduced for the previous programs are used in the net present value program. Over the project operating life interest rate is constant while escalation rates for revenues and expenditures are linear functions. Constant dollar values and base rates refer to the time at which the project construction starts. Capital expenditure is modeled by the beta distribution while revenues and expenditures are confined to uniform cash flows. Time inputs required include construction duration and operating life. Total constant dollar capital expenditure is input as well as yearly average constant dollar cash flows for revenues and expenditures. The marginal attractive rate of return must be input and is held constant. Other required input include the combined federal/provincial tax rate, capital cost allowance rate and owner equity input percentage.

Program output lists variable inputs, current dollar debt at end of construction, current total dollar project construction cost, present worth of cash flows during construction, present worth of cash flows during the operating life and total project net present value.

```
! LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002        **
C
C              NET PRESENT VALUE PROGRAM
C
C ************************************************************
C     THIS PROGRAM CALCULATES THE NET PRESENT VALUE OF
C     A PROJECT ON AN AFTER TAX BASIS
C ************************************************************
C
C ASSUMPTIONS
C     1)LOAN IS TO BE REPAID OVER THE ENTIRE OPERATION PHASE
C     2)REVENUE FUNCTION IS ASSUMED CONSTANT OVER OPERATION
C     3)EXPENSE FUNCTION IS ASSUMED CONSTANT OVER OPERATION
C     4)INFLATION,INTEREST AND MARR REMAIN CONSTANT OVER PROJECT
C     5)NO REPAYMENT ON LOAN DURING CONSTRUCTION
C
C NOTE
C      ALL $ VALUES ARE TO BE ENTERED AS CONSTANT DOLLARS,TIME
C      EQUAL ZERO DOLLARS (THE PROJECT START)
C
C
C ****************VARIABLE LIST*****************************
C      TC-PROJECT CONSTRUCTION DURATION IN YEARS
C     CTC-CONSTANT DOLLAR CAPITAL ESTIMATE
C     P,Q-CONSTANT DOLLAR CASH FLOW PARAMETERS (BETA)
C       F-EQUITY FRACTION OF CURRENT DOLLAR CASH FLOW
C     ERC-CONSTRUCTION BASE INFLATION RATE
C      DE-RATE OF INCREASE OF CONSTRUCTION COST INFLATION
C    MARR-PROJECT MINIMUM ATTRACTIVE RATE OF RETURN
C     PWC-PRESENT WORTH OF CASH FLOWS DURING CONSTRUCTION
C      RC-LOAN INTEREST RATE LEAD OVER INFLATION DURING CONSTRUCT
C  TDOTC-DEBT AT END OF CONSTRUCTION
C      TO-LENGTH OF PROJECT OPERATION IN YEARS
C      TP-TOTAL PROJECT LIFE (TC+TO)
C      RO-LOAN INTEREST RATE DURING OPERATION
C     RPY-CONSTANT DOLLAR REVENUE PER YEAR
C     ERR-BASE INFLATION RATE FOR REVENUES
C    RERR-RATE OF INFLATION INCREASE FOR REVENUES
C     EPY-CONSTANT DOLLAR EXPENSE PER YEAR
C     ERE-INFLATION BASE RATE FOR EXPENSES
C    RERE-RATE OF INFLATION INCREASE FOR EXPENSES
C    TPCC-TOTAL CAPITAL COST;CAPITAL EXPENDITURE,ESCALATION & FIN
C    FPTR-COMBINED FEDERAL/PROVINCIAL TAX RATE
C       D-NOMINAL CAPITAL COST RATE FOR CCA
C     PWR-PRESENT WORTH OF CASH FLOWS DURING OPERATION
C     NPV-NET PRESENT VALUE OF PROJECT
C
C
      DIMENSION CV(20,20)
      REAL MARR,LT,NPV
C
      WRITE(1,5)
    5 FORMAT(1X,/,1X,
     ^'      ****** NET PRESENT VALUE SENSITIVITY ******',/,1X,
     ^'ENTER NUMBER OF CASES')
      READ(1,*)NCASE
      DO 6 IZK=1,NCASE
C
```

```
      WRITE(1,10)
   10 FORMAT(1X,/,10X,'PART 1: THE CONSTRUCTION PHASE',/,1X,
     ^'IN THIS PART THE PRESENT WORTH OF COSTS TO THE OWNER',/,1
     ^'AND TOTAL AMOUNT OWING AT END OF CONSTRUCTION ARE',/,1X,
     ^'CALCULATED')
C
      WRITE(1,20)
   20 FORMAT(1X,/,1X,'ENTER CONSTRUCTION DURATION IN YEARS')
      READ(1,*)TC
C
      WRITE(1,30)
   30 FORMAT(1X,'ENTER CONSTANT DOLLAR CAPITAL COST ESTIMATE')
      READ(1,*)CTC
C
      WRITE(1,40)
   40 FORMAT(1X,'ENTER CONSTANT DOLLAR CASH FLOW BETA PARAMETERS
     ^/,1X,'P=')
      READ(1,*)P
      WRITE(1,50)
   50 FORMAT(1X,'Q=')
      READ(1,*)Q
C
      WRITE(1,60)
   60 FORMAT(1X,'ENTER THE EQUITY INPUT PERCENTAGE')
      READ(1,*)F
      F=F/100.0
C
      WRITE(1,70)
   70 FORMAT(1X,'ENTER BASE RATE OF INFLATION FOR COSTS')
      READ(1,*)ERC
      ERC=ERC/100.0
C
      WRITE(1,75)
   75 FORMAT(1X,'ENTER COSTS INFLATION RATE OF INCREASE ')
      READ(1,*)DE
      DE=DE/100.0
      WRITE(1,80)
   80 FORMAT(1X,'ENTER MINIMUM ATTRACTIVE RATE OF RETURN')
      READ(1,*)MARR
      MARR=MARR/100.0
C
C      CALCULATION OF 1/B EQUALS B1 FOR BETA DISTRIBUTION
C
      QP=Q-P
      CALL GMMA(P,PG,PE)
      CALL GMMA(Q,QG,QE)
      CALL GMMA(QP,QPG,QPE)
      BI=QG/(PG*QPG)
C
      EE1=0.0001
      PP1=P-1
      QPP1=QP-1
C
C
C      CALCULATION OF PRESENT WORTH
C
      CV(1,1)=0.0
```

```
      IF(PP1.EQ.0)CV(1,1)=(TC/2)*((BI*TC**(QP-1))/(TC**(Q-1)))
      IF(QPP1.EQ.0)CV(1,1)=(TC/2)*((BI*TC**(P-1)*EXP((ERC-MARR)*
     ^+0.5*DE*TC**2))/(TC**(Q-1)))
      IF(PP1.EQ.0.AND.QPP1.EQ.0)CV(1,1)=(TC/2)*
     ^((BI/TC**(Q-1))+((BI*EXP((ERC-MARR)*TC+0.5*DE*TC**2))
     ^/(TC**(Q-1))))
      TCH=TC/2.0
      CV(1,2)=(CV(1,1)/2)+TCH*((BI*TCH**(P-1)*(TC-TCH)**(QP-1)
     ^*EXP((ERC-MARR)*TCH+0.5*DE*TCH**2))/(TC**(Q-1)))
      CV(2,1)=(1/3)*(4*CV(1,2)-CV(1,1))
      J1=3
   90 CONTINUE
      DX1=TC/2**(J1-1)
      X1=-1*DX1
      N1=2**(J1-2)
      SUM1=0.0
      I1=1
  100 CONTINUE
      X1=X1+2*DX1
      SUM1=SUM1+(BI*EXP((ERC-MARR)*X1+0.5*DE*X1**2)*
     ^X1**(P-1)*(TC-X1)**
     ^(QP-1))/(TC**(Q-1))
      IF(I1.EQ.N1)GO TO 110
      I1=I1+1
      GO TO 100
  110 CONTINUE
      JJ1=J1-1
      CV(1,J1)=CV(1,JJ1)/2+(DX1*SUM1)
      L1=2
  120 CONTINUE
      K1=J1+1-L1
      L11=L1-1
      K11=K1+1
      CV(L1,K1)=(4**L11*CV(L11,K11)-CV(L11,K1))/(4**L11-1)
      IF(L1.EQ.J1)GO TO 130
      L1=L1+1
      GO TO 120
  130 CONTINUE
      Z1=ABS((CV(J1,1)-CV(JJ1,1))/CV(J1,1))
      IF(Z1.LT.EE1)GO TO 140
      IF(J1.EQ.20)GO TO 140
      J1=J1+1
      GO TO 90
  140 CONTINUE
C
C      PRESENT WORTH OF EQUITY COSTS
C
      PWC=CV(J1,1)*CTC*F
      WRITE(1,150)PWC
  150 FORMAT(1X,/,1X,'PRESENT WORTH OF COSTS =$',F12.2)
C
C     CALCULATION OF TOTAL DOLLARS OWED AT END OF CONSTRUCTION
C
      WRITE(1,160)
  160 FORMAT(1X,/,1X,'ENTER INTEREST RATE LEAD OVER INFLATION',/
     ^'ON BORROWED FUNDS DURING CONSTRUCTION')
      READ(1,*)RC
```

```
      RC=RC/100.0
      RCON=(RC+ERC)*TC+0.5*DE*TC**2
C
      CV(1,1)=0.0
      IF(PP1.EQ.0)CV(1,1)=(TC/2)*((BI*TC**(QP-1)*EXP(RCON))/
     ^(TC**(Q-1)))
      IF(QPP1.EQ.0)CV(1,1)=(TC/2)*((BI*TC**(P-1)*EXP(RCON-RC*TC)
     ^(TC**(Q-1)))
      IF(PP1.EQ.0.AND.QPP1.EQ.0)CV(1,1)=(TC/2)*
     ^((BI*EXP(RCON)/TC**(Q-1))+((BI*EXP(RCON-RC*TC))/
     ^(TC**(Q-1))))
      CV(1,2)=(CV(1,1)/2)+TCH*((BI*TCH**(P-1)*(TC-TCH)**(QP-1)
     ^*EXP(RCON-RC*TCH))/(TC**(Q-1)))
      CV(2,1)=(1/3)*(4*CV(1,2)-CV(1,1))
      J2=3
  170 CONTINUE
      DX2=TC/2**(J2-1)
      X2=-1*DX2
      N2=2**(J2-2)
      SUM2=0.0
      I2=1
  180 CONTINUE
      X2=X2+2*DX2
      SUM2=SUM2+(BI*X2**(P-1)*(TC-X2)**(QP-1)
     ^*EXP(RCON-RC*X2))/(TC**(Q-1))
      IF(I2.EQ.N2)GO TO 190
      I2=I2+1
      GO TO 180
  190 CONTINUE
      JJ2=J2-1
      CV(1,J2)=CV(1,JJ2)/2+(DX2*SUM2)
      L2=2
  200 CONTINUE
      K2=J2+1-L2
      L22=L2-1
      K22=K2+1
      CV(L2,K2)=(4**L22*CV(L22,K22)-CV(L22,K2))/(4**L22-1)
      IF(L2.EQ.J2)GO TO 210
      L2=L2+1
      GO TO 200
  210 CONTINUE
      Z2=ABS((CV(J2,1)-CV(JJ2,1))/CV(J2,1))
      IF(Z2.LT.EE1)GO TO 220
      IF(J2.EQ.20)GO TO 220
      J2=J2+1
      GO TO 170
  220 CONTINUE
C
C           FUNCTION FWTC
C
      FWTC=(1-F)*CV(J2,1)
C
C           TOTAL DOLLARS OWED AT END OF THE CONSTRUCTION PERIOD
C
      TDOTC=CTC*FWTC
C
      WRITE(1,230)TDOTC
```

```
  230 FORMAT(1X,/,1X,'TOTAL AMOUNT OWED END OF CONSTRUCTION =$',
     ^F12.2)
C
C
C
      WRITE(1,240)
  240 FORMAT(1X,/,10X,'PART 2: THE OPERATION PHASE',/,1X,
     ^'IN THIS PART ARE CALCULATED THE RATE OF REPAYMENT',/,1X,
     ^'ON THE OUTSTANDING SUM,THE EXPENDITURE FUNCTION',/,1X,
     ^'AND THE NET PRESENT WORTH OF BENEFITS')
C
      WRITE(1,250)
  250 FORMAT(1X,/,1X,'ENTER THE OPERATION DURATION IN YEARS')
      READ(1,*)TO
C
      WRITE(1,260)
  260 FORMAT(1X,'ENTER LOAN INTEREST RATE DURING OPERATION',
     ^/,1X,'LONG TERM LOAN FIXED RATE')
      READ(1,*)RO
      RO=RO/100.0
C
C         RATE OF LOAN REPAYMENT IS CONSTANT OVER THE OPERATION
C
      EFUN=(RO*EXP(RO*TO))/(EXP(RO*TO)-1)
      LT=CTC*FWTC*EFUN
C
C         REVENUES ARE ASSUMED UNIFORM OVER THE OPERATION
C
      WRITE(1,270)
  270 FORMAT(1X,/,1X,'ENTER CONSTANT DOLLAR REVENUE PER YEAR')
      READ(1,*)RPY
C
      WRITE(1,280)
  280 FORMAT(1X,'ENTER BASE RATE OF INFLATION FOR REVENUES')
      READ(1,*)ERR
      ERR=ERR/100.0
C
      WRITE(1,261)
  261 FORMAT(1X,'ENTER RATE OF INFLATION INCREASE FOR REVENUES')
      READ(1,*)RERR
      RERR=RERR/100.0
C          EXPENSES ARE ASSUMED UNIFORM OVER THE OPERATION
C
      WRITE(1,290)
  290 FORMAT(1X,/,1X,'ENTER CONSTANT DOLLAR EXPENSE PER YEAR')
      READ(1,*)EPY
C
      WRITE(1,300)
  300 FORMAT(1X,'ENTER BASE RATE OF INFLATION FOR EXPENSES')
      READ(1,*)ERE
      ERE=ERE/100.0
C
      WRITE(1,301)
  301 FORMAT(1X,'ENTER RATE OF INFLATION INCREASE FOR EXPENSES')
      READ(1,*)RERE
      RERE=RERE/100.0
C
```

```
: LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002        **
C        TOTAL CAPITAL COST OF PROJECT;TOTAL PAID BY OWNER PLUS
C        AMOUNT OWING AT THE END OF CONSTRUCTION
C
      CV(1,1)=0.0
      IF(PP1.EQ.0)CV(1,1)=(TC/2)*((BI*TC**(QP-1))/(TC**(Q-1)))
      IF(QPP1.EQ.0)CV(1,1)=(TC/2)*((BI*TC**(P-1)*
     ^EXP(ERE*TC+0.5*DE*TC**2))/(TC**(Q-1)))
      IF(PP1.EQ.0.AND.QPP1.EQ.0)CV(1,1)=(TC/2)*
     ^((BI/TC**(Q-1))+((BI*EXP(ERE*TC+0.5*DE*TC**2))/(TC**(Q-1))
      CV(1,2)=(CV(1,1)/2)+TCH*((BI*TCH**(P-1)*(TC-TCH)**(QP-1)
     ^*EXP(ERC*TCH+0.5*DE*TCH**2))/(TC**(Q-1)))
      CV(2,1)=(1/3)*(4*CV(1,2)-CV(1,1))
      J3=3
  310 CONTINUE
      DX3=TC/2**(J3-1)
      X3=-1*DX3
      N3=2**(J3-2)
      SUM3=0.0
      I3=1
  320 CONTINUE
      X3=X3+2*DX3
      SUM3=SUM3+(BI*EXP(ERC*X3+0.5*DE*X3**2)*X3**(P-1)*(TC-X3)**
     ^(QP-1))/(TC**(Q-1))
      IF(I3.EQ.N3)GO TO 330
      I3=I3+1
      GO TO 320
  330 CONTINUE
      JJ3=J3-1
      CV(1,J3)=CV(1,JJ3)/2+(DX3*SUM3)
      L3=2
  340 CONTINUE
      K3=J3+1-L3
      L33=L3-1
      K33=K3+1
      CV(L3,K3)=(4**L33*CV(L33,K33)-CV(L33,K3))/(4**L33-1)
      IF(L3.EQ.J3)GO TO 350
      L3=L3+1
      GO TO 340
  350 CONTINUE
      Z3=ABS((CV(J3,1)-CV(JJ3,1))/CV(J3,1))
      IF(Z3.LT.EE1)GO TO 360
      IF(J3.EQ.20)GO TO 360
      J3=J3+1
      GO TO 310
  360 CONTINUE
      EQTC=F*CV(J3,1)
C
C           TOTAL PROJECT CAPITAL COST
C
      TPCC=CTC*F*CV(J3,1)+TDOTC
C
      WRITE(1,370)TPCC
  370 FORMAT(1X,/,1X,'TOTAL PROJECT CAPITAL COST=$',F15.2)
C
C         CALCULATION OF PRESENT WORTH DURING OPERATION PHASE
C
      WRITE(1,380)
```

```
: LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002          **
    380 FORMAT(1X,/,1X,'ENTER PROJECT TAX RATE')
        READ(1,*)FPTR
        FPTR=FPTR/100.0
C
        WRITE(1,390)
    390 FORMAT(1X,'ENTER THE NOMINAL CAPITAL COST RATE')
        READ(1,*)D
        D=D/100.0
C
C           CONSTANTS OF AFTER TAX CASH FLOW
C
        AP3=FWTC*EFUN
        AP5=TPCC/CTC
C
C           TOTAL PROJECT DURATION
C
        TP=TC+TO
C
C           ROMBERG INTEGRATION OF ATCF(T)*EXP(-MARR*(T-TC))
C
        CALL ATCF(TC,FPTR,RPY,ERR,EPY,ERE,RO,TO,TC,D,CTC,AP3,AP5,
       ^MARR,RERR,RERE,FA)
        CALL ATCF(TP,FPTR,RPY,ERR,EPY,ERE,RO,TO,TC,D,CTC,AP3,AP5,
       ^MARR,RERR,RERE,FB)
        CV(1,1)=((TP-TC)/2)*(FA+FB)
        TAB=((TP+TC)/2)
        CALL ATCF(TAB,FPTR,RPY,ERR,EPY,ERE,RO,TO,TC,D,CTC,AP3,AP5,
       ^MARR,RERR,RERE,FAB)
        CV(1,2)=(CV(1,1)/2)+((TP-TC)/2)*FAB
        CV(2,1)=(1/3)*(4*CV(1,2)-CV(1,1))
        J4=3
    400 CONTINUE
        DX4=(TP-TC)/2**(J4-1)
        X4=TC-DX4
        N4=2**(J4-2)
        SUM4=0.0
        I4=1
    410 CONTINUE
        X4=X4+2*DX4
        CALL ATCF(X4,FPTR,RPY,ERR,EPY,ERE,RO,TO,TC,D,CTC,AP3,AP5,
       ^MARR,RERR,RERE,FX)
        SUM4=SUM4+FX
        IF(I4.EQ.N4)GO TO 420
        I4=I4+1
        GO TO 410
    420 CONTINUE
        JJ4=J4-1
        CV(1,J4)=CV(1,JJ4)/2+(DX4*SUM4)
        L4=2
    430 CONTINUE
        K4=J4+1-L4
        L44=L4-1
        K44=K4+1
        CV(L4,K4)=(4**L44*CV(L44,K44)-CV(L44,K4))/(4**L44-1)
        IF(L4.EQ.J4)GO TO 440
        L4=L4+1
        GO TO 430
```

```
! LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002 ,        **
  440 CONTINUE
      Z4=ABS((CV(J4,1)-CV(JJ4,1))/CV(J4,1))
      IF(Z4.LT.EE1)GO TO 450
      IF(J4.EQ.20)GO TO 450
      J4=J4+1
      GO TO 400
  450 CONTINUE
C
C             PRESENT WORTH DURING OPERATION
C
      PWB=EXP(-MARR*TC)*CV(J4,1)
      WRITE(1,460)PWB
  460 FORMAT(1X,/,1X,'PRESENT WORTH OF OPERATION PHASE=$',F15.2)
C
C        PROJECT NET PRESENT VALUE
C
      NPV=PWB-PWC
C
C
      WRITE(2,500)
  500 FORMAT(1X,/,1X,
     ^'*********************************************************',/,1X,/,
     ^'              PROJECT NET PRESENT VALUE                 ',/,1X,/,
     ^'*********************************************************')
      F=F*100.0
      ERC=ERC*100.0
      DE=DE*100.0
      MARR=MARR*100.0
      RC=RC*100.0
      RO=RO*100.0
      ERR=ERR*100.0
      RERR=RERR*100.0
      ERE=ERE*100.0
      RERE=RERE*100.0
      FPTR=FPTR*100.0
      D=D*100.0
      WRITE(2,510)TC,CTC,P,Q,F,ERC,DE,MARR,RC,TO,RO,RPY,ERR,
     ^RERR,EPY,ERE,RERE,FPTR,D
  510 FORMAT(1X,/,1X,'          VARIABLES ENTERED',/,1X,
     ^'CONSTRUCTION DURATION                          ',F5.2,'YEARS',/
     ^'CONSTANT $ CAPITAL ESTIMATE                   $',F15.2,/,1X,
     ^'CONSTANT $ CASH FLOW PROFILE GIVEN BY   P=',F4.2,/,1X,
     ^'                                        Q=',F4.2,/,1X,
     ^'EQUITY PERCENTAGE OF CURRENT $               ',F6.2,'%',/,1X,
     ^'CONSTRUCTION COSTS BASE INFLATION             ',F6.2,'%',/,1X,
     ^'RATE OF COST INFLATION INCREASE               ',F6.2,'%/YEAR',
     ^'MINIMUM ATTRACTIVE RATE OF RETURN             ',F6.2,'%',/,1X,
     ^'INTEREST RATE LEAD DURING CONSTRUCTION        ',F6.2,'%',/,1X,
     ^'LENGTH OF PROJECT OPERATION DURATION          ',F5.2,'YEARS',/
     ^'INTEREST RATE DURING OPERATION PHASE          ',F6.2,'%',/,1X,
     ^'ANNUAL REVENUE IN CONSTANT $                 $',F15.2,/,1X,
     ^'BASE INFLATION RATE OF REVENUES               ',F6.2,'%',/,1X,
     ^'RATE OF REVENUES INFLATION INCREASE           ',F6.2,'%/YR.',/
     ^'ANNUAL EXPENSES IN CONSTANT DOLLARS          $',F15.2,/,1X,
     ^'BASE INFLATION RATE OF EXPENSES               ',F6.2,'%',/,1X,
     ^'RATE OF EXPENSES INFLATION INCREASE           ',F6.2,'%/YR.'/,
     ^'FEDERAL/PROVINCIAL TAX RATE                   ',F6.2,'%',/,1X,
```

```
! LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002        **
        ^'CAPITAL COST RATE                              ',F6.2,'%')
         WRITE(2,520)TP,TDOTC,TPCC,PWC,PWB,NPV
     520 FORMAT(1X,/,1X,'          RESULTS',/,1X,
        ^'TOTAL PROJECT LIFE                             ',F5.2,'YEARS',
        ^'DEBT AT END OF CONSTRUCTION (CURRENT)     $',F15.2,/,1X,
        ^'PROJECT TOTAL CAPITAL COST (CURRENT)      $',F15.2,/,1X,
        ^'PRESENT WORTH OF CONSTRUCTION CASH FLOW $',F15.2,/,1X,
        ^'PRESENT WORTH OF OPERATION CASH FLOWS   $',F15.2,/,1X,/,1
        ^'PROJECT NET PRESENT VALUE                 $',F15.2)
   C
       6 CONTINUE
   C
         STOP
         END

7D  R04-00     MAINPROG    .MAIN     26/11/82  16:25:28  TABLE SPAC
FFER:   20 LINES/1321 BYTES    STACK SPACE: 231 WORDS
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
C
C       PROGRAM FOR GAMMA FUNCTION
C
      SUBROUTINE GMMA(XX,GX,IER)
      IF(XX-57.)20,20,25
   25 IER=2
      GX=1.E75
      RETURN
   20 X=XX
      ERR=1.0E-6
      IER=0
      GX=1.0
      IF(X-2.0)30,30,35
   40 IF(X-2.0)45,45,35
   35 X=X-1.0
      GX=GX*X
      GO TO 40
   30 IF(X-1.0)50,55,45
   50 IF(X-ERR)60,60,65
   60 Y=FLOAT(INT(X))-X
      IF(ABS(Y)-ERR)70,70,75
   75 IF(1.0-Y-ERR)70,70,80
   80 IF(X-1.0)65,65,45
   65 GX=GX/X
      X=X+1.0
      GO TO 80
   45 Y=X-1.0
      GY=1.0+Y*(-0.5771017+Y*(0.9858540+Y*(-0.8764218
     ^+Y*(0.8328212+Y*(-0.5684729+Y*(0.2548205
     ^+Y*(-0.05149930)))))))
      GX=GX*GY
   55 RETURN
   70 IER=1
      RETURN
      END

7D  R04-00     SUBROUTINE  GMMA      26/11/82  16:25:29  TABLE SPAC
FFER:   20 LINES/1321 BYTES    STACK SPACE: 297 WORDS
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
      C
      C          AFTER TAX CASH FLOW FUNCTION CALCULATION
      C
            SUBROUTINE ATCF(T,FPTR,RPY,ERR,EPY,ERE,RO,TO,TC,D,CTC,AP3,
           *AP5,MARR,RERR,RERE,ATCINT)
            REAL MARR
            AP1=(1-FPTR)*(RPY*EXP(ERR*T+0.5*RERR*T**2)
           *-EPY*EXP(ERE*T+0.5*RERE*T**2))
            AP2=1+FPTR*(EXP(-RO*TO)-EXP(-RO*(T-TC)))
            AP4=D*(1-D)**(T-TC-1)
            ATCFT=AP1-CTC*((AP3*AP2)-FPTR*(AP5*AP4))
            ATCINT=ATCFT*EXP(-MARR*(T-TC))
            RETURN
            END

'7D  R04-00      SUBROUTINE  ATCF       26/11/82  16:25:30   TABLE SPAC
IFFER:   20 LINES/1321 BYTES    STACK SPACE: 163 WORDS
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

A-4 BREAKEVEN VALUE PROGRAM: NPV

This program uses the same assumptions and requires the same inputs as the net present value program except that all escalation functions are constant; they are specified by a base rate only. In this breakeven program values are calculated for any construction duration entered with the first entry being the estimated construction duration. Data for a breakeven curve can be created by entering enough duration values to define the breakeven curve.

```
 LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002        **
C
C             NET PRESENT VALUE PROGRAM
C        CONSTANT DOLLAR CAPITAL COST BREAKEVEN
C
C ***********************************************************
C     THIS PROGRAM CALCULATES THE CONSTANT DOLLAR CAPITAL
C     ESTIMATES REQUIRED SO THAT THE VALUE OF NPV(TC) REMAINS
C     CONSTANT AT NPV(TC*) FOR ANY TC
C ***********************************************************
C
C ASSUMPTIONS
C     1)LOAN IS TO BE REPAID OVER THE ENTIRE OPERATION PHASE
C     2)REVENUE FUNCTION IS ASSUMED CONSTANT OVER OPERATION
C     3)EXPENSE FUNCTION IS ASSUMED CONSTANT OVER OPERATION
C     4)INFLATION,INTEREST AND MARR REMAIN CONSTANT OVER PROJECT
C     5)NO REPAYMENT ON LOAN DURING CONSTRUCTION
C
C NOTE
C      ALL $ VALUES ARE TO BE ENTERED AS CONSTANT DOLLARS,TIME
C      EQUAL ZERO DOLLARS (THE PROJECT START)
C
C
C ****************VARIABLE LIST*******************************
C      TC-PROJECT CONSTRUCTION DURATION IN YEARS
C     CTC-CONSTANT DOLLAR CAPITAL ESTIMATE
C     P,Q-CONSTANT DOLLAR CASH FLOW PARAMETERS (BETA)
C       F-EQUITY FRACTION OF CURRENT DOLLAR CASH FLOW
C     ERC-CONSTRUCTION INFLATION RATE
C    MARR-PROJECT MINIMUM ATTRACTIVE RATE OF RETURN
C     PWC-PRESENT WORTH OF CASH FLOWS DURING CONSTRUCTION
C      RC-LOAN INTEREST RATE DURING CONSTRUCTION
C   TDOTC-DEBT AT END OF CONSTRUCTION
C      TO-LENGTH OF PROJECT OPERATION IN YEARS
C      TP-TOTAL PROJECT LIFE (TC+TO)
C      RO-LOAN INTEREST RATE DURING OPERATION
C     RPY-CONSTANT DOLLAR REVENUE PER YEAR
C     ERR-INFLATION RATE FOR REVENUES
C     EPY-CONSTANT DOLLAR EXPENSE PER YEAR
C     ERE-INFLATION RATE FOR EXPENSES
C    TPCC-TOTAL CAPITAL COST;CAPITAL EXPENDITURE,ESCALATION & FIN
C    FPTR-COMBINED FEDERAL/PROVINCIAL TAX RATE
C       D-NOMINAL CAPITAL COST RATE FOR CCA
C     PWB-PRESENT WORTH OF CASH FLOWS DURING OPERATION
C     NPV-NET PRESENT VALUE OF PROJECT
C
C
      DIMENSION CV(20,20),TCC(10),FCFT(10),FWTC(10),EQTC(10),
     ^XFUNC(10),YFUNC(10),CBTC(10)
      REAL MARR,LT,NPV
C
      WRITE(1,10)
   10 FORMAT(1X,/,10X,'PART 1: THE CONSTRUCTION PHASE',/,1X,
     ^'IN THIS PART THE PRESENT WORTH OF COSTS TO THE OWNER',/,1
     ^'AND TOTAL AMOUNT OWING AT END OF CONSTRUCTION ARE',/,1X,
     ^'CALCULATED')
C
      WRITE(1,15)
```

```
   15 FORMAT(1X,/,1X,'ENTER NUMBER OF DURATIONS BEING CONSIDERED
      READ(1,*)ND
      DO 17 IC=1,ND
      WRITE(1,20)IC
   20 FORMAT(1X,/,1X,'ENTER CONSTRUCTION DURATION FOR CASE ',I2)
      READ(1,*)TCC(IC)
   17 CONTINUE
C
      WRITE(1,30)
   30 FORMAT(1X,'FOR TCC(1) ENTER CAPITAL COST ESTIMATE')
      READ(1,*)CTC
C
      WRITE(1,40)
   40 FORMAT(1X,'ENTER CONSTANT DOLLAR CASH FLOW BETA PARAMETERS
     ^/,1X,'P=')
      READ(1,*)P
      WRITE(1,50)
   50 FORMAT(1X,'Q=')
      READ(1,*)Q
C
      WRITE(1,60)
   60 FORMAT(1X,'ENTER THE EQUITY INPUT PERCENTAGE')
      READ(1,*)F
      F=F/100.0
C
      WRITE(1,70)
   70 FORMAT(1X,'ENTER RATE OF INFLATION FOR COSTS')
      READ(1,*)ERC
      ERC=ERC/100.0
C
      WRITE(1,80)
   80 FORMAT(1X,'ENTER MINIMUM ATTRACTIVE RATE OF RETURN')
      READ(1,*)MARR
      MARR=MARR/100.0
C
C      CALCULATION OF 1/B EQUALS B1 FOR BETA DISTRIBUTION
C
      QP=Q-P
      CALL GMMA(P,PG,PE)
      CALL GMMA(Q,QG,QE)
      CALL GMMA(QP,QPG,QPE)
      BI=QG/(PG*QPG)
C
      EE1=0.0001
      PP1=P-1
      QPP1=QP-1
C
C
C      CALCULATION OF PRESENT WORTH
C
      DO 85 JC=1,ND
      TC=TCC(JC)
      CV(1,1)=0.0
      IF(PP1.EQ.0)CV(1,1)=(TC/2)*((BI*TC**(QP-1))/(TC**(Q-1)))
      IF(QPP1.EQ.0)CV(1,1)=(TC/2)*((BI*TC**(P-1)*EXP((ERC-MARR)*
     ^/(TC**(Q-1)))
      IF(PP1.EQ.0.AND.QPP1.EQ.0)CV(1,1)=(TC/2)*
```

```
! LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002              **
      ^((BI/TC**(Q-1))+((BI*EXP((ERC-MARR)*TC))/(TC**(Q-1))))
       TCH=TC/2.0
       CV(1,2)=(CV(1,1)/2)+TCH*((BI*TCH**(P-1)*(TC-TCH)**(QP-1)
      ^*EXP((ERC-MARR)*TCH))/(TC**(Q-1)))
       CV(2,1)=(1/3)*(4*CV(1,2)-CV(1,1))
       J1=3
    90 CONTINUE
       DX1=TC/2**(J1-1)
       X1=-1*DX1
       N1=2**(J1-2)
       SUM1=0.0
       I1=1
   100 CONTINUE
       X1=X1+2*DX1
       SUM1=SUM1+(BI*EXP((ERC-MARR)*X1)*X1**(P-1)*(TC-X1)**
      ^(QP-1))/(TC**(Q-1))
       IF(I1.EQ.N1)GO TO 110
       I1=I1+1
       GO TO 100
   110 CONTINUE
       JJ1=J1-1
       CV(1,J1)=CV(1,JJ1)/2+(DX1*SUM1)
       L1=2
   120 CONTINUE
       K1=J1+1-L1
       L11=L1-1
       K11=K1+1
       CV(L1,K1)=(4**L11*CV(L11,K11)-CV(L11,K1))/(4**L11-1)
       IF(L1.EQ.J1)GO TO 130
       L1=L1+1
       GO TO 120
   130 CONTINUE
       Z1=ABS((CV(J1,1)-CV(JJ1,1))/CV(J1,1))
       IF(Z1.LT.EE1)GO TO 140
       IF(J1.EQ.20)GO TO 140
       J1=J1+1
       GO TO 90
   140 CONTINUE
       FCFT(JC)=CV(J1,1)*F
    85 CONTINUE
C
C       PRESENT WORTH OF EQUITY COSTS
C
       PWC=CTC*FCFT(1)
       WRITE(1,150)PWC
   150 FORMAT(1X,/,1X,'PRESENT WORTH OF COSTS =$',F12.2)
C
C      CALCULATION OF TOTAL DOLLARS OWED AT END OF CONSTRUCTION
C
       WRITE(1,160)
   160 FORMAT(1X,/,1X,'ENTER INTEREST RATE ON BORROWED MONEY',/,1
      ^'DURING THE CONSTRUCTION PHASE')
       READ(1,*)RC
       RC=RC/100.0
C
       DO 165 KC=1,ND
       TC=TCC(KC)
```

```
      CV(1,1)=0.0
      IF(PP1.EQ.0)CV(1,1)=(TC/2)*((BI*TC**(QP-1)*EXP(RC*TC))/
     ^(TC**(Q-1)))
      IF(QPP1.EQ.0)CV(1,1)=(TC/2)*((BI*TC**(P-1)*EXP(ERC*TC))/
     ^(TC**(Q-1)))
      IF(PP1.EQ.0.AND.QPP1.EQ.0)CV(1,1)=(TC/2)*
     ^((BI*EXP(RC*TC)/TC**(Q-1))+((BI*EXP(ERC*TC))/
     ^(TC**(Q-1))))
      CV(1,2)=(CV(1,1)/2)+TCH*((BI*TCH**(P-1)*(TC-TCH)**(QP-1)
     ^*EXP((ERC-RC)*TCH+RC*TC))/(TC**(Q-1)))
      CV(2,1)=(1/3)*(4*CV(1,2)-CV(1,1))
      J2=3
  170 CONTINUE
      DX2=TC/2**(J2-1)
      X2=-1*DX2
      N2=2**(J2-2)
      SUM2=0.0
      I2=1
  180 CONTINUE
      X2=X2+2*DX2
      SUM2=SUM2+(BI*X2**(P-1)*(TC-X2)**(QP-1)
     ^*EXP((ERC-RC)*X2+RC*TC))/(TC**(Q-1))
      IF(I2.EQ.N2)GO TO 190
      I2=I2+1
      GO TO 180
  190 CONTINUE
      JJ2=J2-1
      CV(1,J2)=CV(1,JJ2)/2+(DX2*SUM2)
      L2=2
  200 CONTINUE
      K2=J2+1-L2
      L22=L2-1
      K22=K2+1
      CV(L2,K2)=(4**L22*CV(L22,K22)-CV(L22,K2))/(4**L22-1)
      IF(L2.EQ.J2)GO TO 210
      L2=L2+1
      GO TO 200
  210 CONTINUE
      Z2=ABS((CV(J2,1)-CV(JJ2,1))/CV(J2,1))
      IF(Z2.LT.EE1)GO TO 220
      IF(J2.EQ.20)GO TO 220
      J2=J2+1
      GO TO 170
  220 CONTINUE
C
C             FUNCTION FWTC .
C
      FWTC(KC)=(1-F)*CV(J2,1)
  165 CONTINUE
C
C             TOTAL DOLLARS OWED AT END OF THE CONSTRUCTION PERIOD
C
      TDOTC=CTC*FWTC(1)
C
      WRITE(1,230)TDOTC
  230 FORMAT(1X,/,1X,'TOTAL AMOUNT OWED END OF CONSTRUCTION =$',
     ^F12.2)
```

```
C
C
C
      WRITE(1,240)
  240 FORMAT(1X,/,10X,'PART 2: THE OPERATION PHASE',/,1X,
     ^'IN THIS PART ARE CALCULATED THE RATE OF REPAYMENT',/,1X,
     ^'ON THE OUTSTANDING SUM,THE EXPENDITURE FUNCTION',/,1X,
     ^'AND THE NET PRESENT WORTH OF BENEFITS')
C
      WRITE(1,250)
  250 FORMAT(1X,/,1X,'ENTER THE OPERATION DURATION IN YEARS')
      READ(1,*)TO
C
      WRITE(1,260)
  260 FORMAT(1X,'ENTER LOAN INTEREST RATE DURING OPERATION')
      READ(1,*)RO
      RO=RO/100.0
C
C         RATE OF LOAN REPAYMENT IS CONSTANT OVER THE OPERATION
C
      EFUN=(RO*EXP(RO*TO))/(EXP(RO*TO)-1)
      LT=CTC*FWTC(1)*EFUN
C
C         REVENUES ARE ASSUMED UNIFORM OVER THE OPERATION
C
      WRITE(1,270)
  270 FORMAT(1X,/,1X,'ENTER CONSTANT DOLLAR REVENUE PER YEAR')
      READ(1,*)RPY
C
      WRITE(1,280)
  280 FORMAT(1X,'ENTER RATE OF INFLATION FOR REVENUES')
      READ(1,*)ERR
      ERR=ERR/100.0
C
C          EXPENSES ARE ASSUMED UNIFORM OVER THE OPERATION
C
      WRITE(1,290)
  290 FORMAT(1X,/,1X,'ENTER CONSTANT DOLLAR EXPENSE PER YEAR')
      READ(1,*)EPY
C
      WRITE(1,300)
  300 FORMAT(1X,'ENTER RATE OF INFLATION FOR EXPENSES')
      READ(1,*)ERE
      ERE=ERE/100.0
C
C       TOTAL CAPITAL COST OF PROJECT:TOTAL PAID BY OWNER PLUS
C       AMOUNT OWING AT THE END OF CONSTRUCTION
C
      DO 305 LC=1,ND
      TC=TCC(LC)
      CV(1,1)=0.0
      IF(PP1.EQ.0)CV(1,1)=(TC/2)*((BI*TC**(QP-1))/(TC**(Q-1)))
      IF(QPP1.EQ.0)CV(1,1)=(TC/2)*((BI*TC**(P-1)*EXP(ERC*TC))/
     ^(TC**(Q-1)))
      IF(PP1.EQ.0.AND.QPP1.EQ.0)CV(1,1)=(TC/2)*
     ^((BI/TC**(Q-1))+((BI*EXP(ERC*TC))/(TC**(Q-1))))
      CV(1,2)=(CV(1,1)/2)+TCH*((BI*TCH**(P-1)*(TC-TCH)**(QP-1)
```

```
     ^*EXP(ERC*TCH))/(TC**(Q-1)))
      CV(2,1)=(1/3)*(4*CV(1,2)-CV(1,1))
      J3=3
  310 CONTINUE
      DX3=TC/2**(J3-1)
      X3=-1*DX3
      N3=2**(J3-2)
      SUM3=0.0
      I3=1
  320 CONTINUE
      X3=X3+2*DX3
      SUM3=SUM3+(BI*EXP(ERC*X3)*X3**(P-1)*(TC-X3)**
     ^(QP-1))/(TC**(Q-1))
      IF(I3.EQ.N3)GO TO 330
      I3=I3+1
      GO TO 320
  330 CONTINUE
      JJ3=J3-1
      CV(1,J3)=CV(1,JJ3)/2+(DX3*SUM3)
      L3=2
  340 CONTINUE
      K3=J3+1-L3
      L33=L3-1
      K33=K3+1
      CV(L3,K3)=(4**L33*CV(L33,K33)-CV(L33,K3))/(4**L33-1)
      IF(L3.EQ.J3)GO TO 350
      L3=L3+1
      GO TO 340
  350 CONTINUE
      Z3=ABS((CV(J3,1)-CV(JJ3,1))/CV(J3,1))
      IF(Z3.LT.EE1)GO TO 360
      IF(J3.EQ.20)GO TO 360
      J3=J3+1
      GO TO 310
  360 CONTINUE
      EQTC(LC)=F*CV(J3,1)
  305 CONTINUE
C
C           TOTAL PROJECT CAPITAL COST
C
      TPCC=CTC*EQTC(1)+TDOTC
C
      WRITE(1,370)TPCC
  370 FORMAT(1X,/,1X,'TOTAL PROJECT CAPITAL COST=$',F15.2)
C
C         CALCULATION OF PRESENT WORTH DURING OPERATION PHASE
C
      WRITE(1,380)
  380 FORMAT(1X,/,1X,'ENTER PROJECT TAX RATE')
      READ(1,*)FPTR
      FPTR=FPTR/100.0
C
      WRITE(1,390)
  390 FORMAT(1X,'ENTER THE NOMINAL CAPITAL COST RATE')
      READ(1,*)D
      D=D/100.0
C
```

```
C          CONSTANTS OF AFTER TAX CASH FLOW
C
      AP3=FWTC(1)*EFUN
      AP5=EQTC(1)+FWTC(1)
C
C          TOTAL PROJECT DURATION
C
      TC=TCC(1)
      TP=TC+TD
C
C          ROMBERG INTEGRATION OF ATCF(T)*EXP(-MARR*(T-TC))
C
      CALL ATCF(TC,FPTR,RPY,ERR,EPY,ERE,RO,TO,TC,D,CTC,AP3,AP5,
     ^MARR,FA)
      CALL ATCF(TP,FPTR,RPY,ERR,EPY,ERE,RO,TO,TC,D,CTC,AP3,AP5,
     ^MARR,FB)
      CV(1,1)=((TP-TC)/2)*(FA+FB)
      TAB=((TP+TC)/2)
      CALL ATCF(TAB,FPTR,RPY,ERR,EPY,ERE,RO,TO,TC,D,CTC,AP3,AP5,
     ^MARR,FAB)
      CV(1,2)=(CV(1,1)/2)+((TP-TC)/2)*FAB
      CV(2,1)=(1/3)*(4*CV(1,2)-CV(1,1))
      J4=3
  400 CONTINUE
      DX4=(TP-TC)/2**(J4-1)
      X4=TC-DX4
      N4=2**(J4-2)
      SUM4=0.0
      I4=1
  410 CONTINUE
      X4=X4+2*DX4
      CALL ATCF(X4,FPTR,RPY,ERR,EPY,ERE,RO,TO,TC,D,CTC,AP3,AP5,
     ^MARR,FX)
      SUM4=SUM4+FX
      IF(I4.EQ.N4)GO TO 420
      I4=I4+1
      GO TO 410
  420 CONTINUE
      JJ4=J4-1
      CV(1,J4)=CV(1,JJ4)/2+(DX4*SUM4)
      L4=2
  430 CONTINUE
      K4=J4+1-L4
      L44=L4-1
      K44=K4+1
      CV(L4,K4)=(4**L44*CV(L44,K44)-CV(L44,K4))/(4**L44-1)
      IF(L4.EQ.J4)GO TO 440
      L4=L4+1
      GO TO 430
  440 CONTINUE
      Z4=ABS((CV(J4,1)-CV(JJ4,1))/CV(J4,1))
      IF(Z4.LT.EE1)GO TO 450
      IF(J4.EQ.20)GO TO 450
      J4=J4+1
      GO TO 400
  450 CONTINUE
C
```

```
C              PRESENT WORTH DURING OPERATION
C
      PWB=EXP(-MARR*TC)*CV(J4,1)
      WRITE(1,460)PWB
  460 FORMAT(1X,/,1X,'PRESENT WORTH OF OPERATION PHASE=$',F15.2)
C
C       PROJECT NET PRESENT VALUE
C
      NPV=PWB-PWC
C
C
      WRITE(2,500)
  500 FORMAT(1X,/,1X,
     ^'**********************************************',/,1X,/,
     ^'          PROJECT NET PRESENT VALUE           ',/,1X,/,
     ^'**********************************************')
      F=F*100.0
      ERC=ERC*100.0
      MARR=MARR*100.0
      RC=RC*100.0
      RO=RO*100.0
      ERR=ERR*100.0
      ERE=ERE*100.0
      FPTR=FPTR*100.0
      D=D*100.0
      WRITE(2,510)TC,CTC,P,Q,F,ERC,MARR,RC,TD,RO,RPY,ERR,EPY,
     ^ERE,FPTR,D
  510 FORMAT(1X,/,1X,'         VARIABLES ENTERED',/,1X,
     ^'CONSTRUCTION DURATION                        ',F5.2,'YEARS',
     ^'CONSTANT $ CAPITAL ESTIMATE                 $',F15.2,/,1X,
     ^'CONSTANT $ CASH FLOW PROFILE GIVEN BY  P=',F4.2,/,1X,
     ^'                                       Q=',F4.2,/,1X,
     ^'EQUITY PERCENTAGE OF CURRENT $              ',F6.2,'%',/,1X,
     ^'CONSTRUCTION COSTS INFLATION RATE           ',F6.2,'%',/,1X,
     ^'PROJECT MINIMUM ATTRACTIVE RATE OF RETURN',F6.2,'%',/,1X,
     ^'INTEREST RATE DURING CONSTRUCTION           ',F6.2,'%',/,1X,
     ^'LENGTH OF OPERATION DURATION                ',F5.2,'YEARS',/
     ^'INTEREST RATE DURING OPERATION              ',F6.2,'%',/,1X,
     ^'ANNUAL REVENUE IN CONSTANT DOLLARS         $',F15.2,/,1X,
     ^'INFLATION RATE OF REVENUES                  ',F6.2,'%',/,1X,
     ^'ANNUAL EXPENSES IN CONSTANT DOLLARS        $',F15.2,/,1X,
     ^'INFLATION RATE OF EXPENSES                  ',F6.2,'%',/,1X,
     ^'FEDERAL/PROVINCIAL TAX RATE                 ',F6.2,'%',/,1X,
     ^'CAPITAL COST RATE                           ',F6.2,'%')
      WRITE(2,520)TP,TDOTC,TPCC,PWC,PWB,NPV
  520 FORMAT(1X,/,1X,'          RESULTS',/,1X,
     ^'TOTAL PROJECT LIFE                          ',F5.2,'YEARS',
     ^'DEBT AT END OF CONSTRUCTION (CURRENT)      $',F15.2,/,1X,
     ^'PROJECT TOTAL CAPITAL COST (CURRENT)       $',F15.2,/,1X,
     ^'PRESENT WORTH OF CONSTRUCTION CASH FLOW $',F15.2,/,1X,
     ^'PRESENT WORTH OF OPERATION CASH FLOWS   $',F15.2,/,1X,/,1
     ^'PROJECT NET PRESENT VALUE                  $',F15.2)
C
      F=F/100.0
      ERC=ERC/100.0
      MARR=MARR/100.0
      RC=RC/100.0
```

```
      RO=RO/100.0
      ERR=ERR/100.0
      ERE=ERE/100.0
      FPTR=FPTR/100.0
      D=D/100.0
C
      DO 590 MD=2,ND
      TC=TCC(MD)
      TP=TC+TO
      CALL CAPX(TC,RPY,ERR,EPY,ERE,FPTR,MARR,TC,FA1)
      CALL CAPX(TP,RPY,ERR,EPY,ERE,FPTR,MARR,TC,FB1)
      CV(1,1)=((TP-TC)/2)*(FA1+FB1)
      TAB=((TP+TC)/2)
      CALL CAPX(TAB,RPY,ERR,EPY,ERE,FPTR,MARR,TC,FAB1)
      CV(1,2)=(CV(1,1)/2)+((TP-TC)/2)*FAB1
      CV(2,1)=(1/3)*(4*CV(1,2)-CV(1,1))
      J5=3
  600 CONTINUE
      DX5=(TP-TC)/2**(J5-1)
      X5=TC-DX5
      N5=2**(J5-2)
      SUM5=0.0
      I5=1
  610 CONTINUE
      X5=X5+2*DX5
      CALL CAPX(X5,RPY,ERR,EPY,ERE,FPTR,MARR,TC,FX1)
      SUM5=SUM5+FX1
      IF(I5.EQ.N5)GO TO 620
      I5=I5+1
      GO TO 610
  620 CONTINUE
      JJ5=J5-1
      CV(1,J5)=CV(1,JJ5)/2+(DX5*SUM5)
      L5=2
  630 CONTINUE
      K5=J5+1-L5
      L55=L5-1
      K55=K5+1
      CV(L5,K5)=(4**L55*CV(L55,K55)-CV(L55,K5))/(4**L55-1)
      IF(L5.EQ.J5)GO TO 640
      L5=L5+1
      GO TO 630
  640 CONTINUE
      Z5=ABS((CV(J5,1)-CV(JJ5,1))/CV(J5,1))
      IF(Z5.LT.EE1)GO TO 650
      IF(J5.EQ.20)GO TO 650
      J5=J5+1
      GO TO 600
  650 CONTINUE
      XFUNC(MD)=CV(J5,1)
  590 CONTINUE
C
C
C
      DO 690 MDZ=2,ND
      TC=TCC(MDZ)
      TP=TC+TO
```

```
      FFWTC=FWTC(MDZ)
      EEQTC=EQTC(MDZ)
      CALL CAPY(TC,TO,FFWTC,EFUN,FPTR,RO,EEQTC,D,MARR,TC,FA2)
      CALL CAPY(TP,TO,FFWTC,EFUN,FPTR,RO,EEQTC,D,MARR,TC,FB2)
      CV(1,1)=((TP-TC)/2)*(FA2+FB2)
      TAB=((TP+TC)/2)
      CALL CAPY(TAB,TO,FFWTC,EFUN,FPTR,RO,EEQTC,D,MARR,TC,FAB2)
      CV(1,2)=(CV(1,1)/2)+((TP-TC)/2)*FAB2
      CV(2,1)=(1/3)*(4*CV(1,2)-CV(1,1))
      J6=3
  700 CONTINUE
      DX6=(TP-TC)/2**(J6-1)
      X6=TC-DX6
      N6=2**(J6-2)
      SUM6=0.0
      I6=1
  710 CONTINUE
      X6=X6+2*DX6
      CALL CAPY(X6,TO,FFWTC,EFUN,FPTR,RO,EEQTC,D,MARR,TC,FX2)
      SUM6=SUM6+FX2
      IF(I6.EQ.N6)GO TO 720
      I6=I6+1
      GO TO 710
  720 CONTINUE
      JJ6=J6-1
      CV(1,J6)=CV(1,JJ6)/2+(DX6*SUM6)
      L6=2
  730 CONTINUE
      K6=J6+1-L6
      L66=L6-1
      K66=K6+1
      CV(L6,K6)=(4**L66*CV(L66,K66)-CV(L66,K6))/(4**L66-1)
      IF(L6.EQ.J6)GO TO 740
      L6=L6+1
      GO TO 730
  740 CONTINUE
      Z6=ABS((CV(J6,1)-CV(JJ6,1))/CV(J6,1))
      IF(Z6.LT.EE1)GO TO 750
      IF(J6.EQ.20)GO TO 750
      J6=J6+1
      GO TO 700
  750 CONTINUE
      YFUNC(MDZ)=CV(J6,1)
  690 CONTINUE
C
C       CALCULATION OF BREAKEVEN COSTS
C
      DO 800 NCC=2,ND
      TC=TCC(NCC)
      CBTOP=NPV-EXP(-MARR*TC)*XFUNC(NCC)
      CBBOT=(-1)*(FCFT(NCC)+EXP(-MARR*TC)*YFUNC(NCC))
      CBTC(NCC)=CBTOP/CBBOT
  800 CONTINUE
C
      WRITE(2,810)
  810 FORMAT(1X,/,1X,/,1X,'          BREAKEVEN ANALYSIS RESULTS'
C
```

```
      WRITE(2,820)TCC(1),CTC
  820 FORMAT(1X,'FOR ORIGINAL DURATION ',F5.2,' YEARS',/,1X,
     *'THE CAPITAL COST IS $',F15.2)
C
      WRITE(2,830)
  830 FORMAT(1X,/,1X,
     *'NEW DURATION            ALLOWABLE CAPITAL COST')
C
      DO 840 NCAA=2,ND
      WRITE(2,850)TCC(NCAA),CBTC(NCAA)
  850 FORMAT(1X,3X,F5.2,' YEARS',11X,'$',F15.2)
  840 CONTINUE
      STOP
      END
```

```
7D  R04-00      MAINPROG     .MAIN      26/11/82  16:26:07  TABLE SPAC
FFER:  20 LINES/1321 BYTES    STACK SPACE: 231 WORDS
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
C
C       PROGRAM FOR GAMMA FUNCTION
C
      SUBROUTINE GMMA(XX,GX,IER)
      IF(XX-57.)20,20,25
   25 IER=2
      GX=1.E75
      RETURN
   20 X=XX
      ERR=1.0E-6
      IER=0
      GX=1.0
      IF(X-2.0)30,30,35
   40 IF(X-2.0)45,45,35
   35 X=X-1.0
      GX=GX*X
      GO TO 40
   30 IF(X-1.0)50,55,45
   50 IF(X-ERR)60,60,65
   60 Y=FLOAT(INT(X))-X
      IF(ABS(Y)-ERR)70,70,75
   75 IF(1.0-Y-ERR)70,70,80
   80 IF(X-1.0)65,65,45
   65 GX=GX/X
      X=X+1.0
      GO TO 80
   45 Y=X-1.0
      GY=1.0+Y*(-0.5771017+Y*(0.9858540+Y*(-0.8764218
     "+Y*(0.8328212+Y*(-0.5684729+Y*(0.2548205
     "+Y*(-0.05149930)))))))
      GX=GX*GY
   55 RETURN
   70 IER=1
      RETURN
      END
```

7D R04-00   SUBROUTINE GMMA   26/11/82 16:26:08 TABLE SPAC
FFER: 20 LINES/1321 BYTES   STACK SPACE: 297 WORDS
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

```
C
C          AFTER TAX CASH FLOW FUNCTION CALCULATION
C
      SUBROUTINE ATCF(T,FPTR,RPY,ERR,EPY,ERE,RO,TO,TC,D,CTC,AP3,
     *AP5,MARR,ATCINT)
      REAL MARR
      AP1=(1-FPTR)*(RPY*EXP(ERR*T)-EPY*EXP(ERE*T))
      AP2=1+FPTR*(EXP(-RO*TO)-EXP(-RO*(T-TC)))
      AP4=D*(1-D)**(T-TC-1)
      ATCFT=AP1-CTC*((AP3*AP2)-FPTR*(AP5*AP4))
      ATCINT=ATCFT*EXP(-MARR*(T-TC))
      RETURN
      END

7D  R04-00    SUBROUTINE  ATCF      26/11/82  16:26:09  TABLE SPAC
FFER:   20 LINES/1321 BYTES     STACK SPACE: 163 WORDS
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
C
      SUBROUTINE CAPX(T,RPY,ERR,EPY,ERE,FPTR,MARR,TC,CAPIX)
      REAL MARR
      CX1=RPY*EXP(ERR*T)-EPY*EXP(ERE*T)
      CX2=1-FPTR
      CX3=EXP(-MARR*(T-TC))
      CAPIX=CX1*CX2*CX3
      RETURN
      END

'D  R04-00     SUBROUTINE  CAPX       26/11/82  16:26:09  TABLE SPAC
'FER:   20 LINES/1321 BYTES    STACK SPACE: 124 WORDS
3ION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
C
      SUBROUTINE CAPY(T,TO,FWTCN,EFUN,FPTR,RO,EQTCN,D,MARR,TC,
     ^CAPIY)
      REAL MARR
      CY1=FWTCN*EFUN
      CY2=1+FPTR*(EXP(-RO*TO)-EXP(-RO*(T-TC)))
      CY3=FPTR*(FWTCN+EQTCN)
      CY4=D*(1-D)**(T-TC-1)
      CAPIY=CY1*CY2-CY3*CY4
      CAPIY=CAPIY*EXP(-MARR*(T-TC))
      RETURN
      END
```

'D R04-00 SUBROUTINE CAPY 26/11/82 16:26:10 TABLE SPAC
'FER: 20 LINES/1321 BYTES STACK SPACE: 163 WORDS
ION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

APPENDIX B

MICRO MODEL PROGRAM

The Micro Model computer program consists of two parts. The first, Program 1, calculates operation duration given a normalized productivity and manpower profile. Program 1 is capable of handling only one operation at a time. The second program, labelled the Activity Model, uses the entered results of Program 1 to create activity cash flow and manpower. Program 2 may also be used independently of Program 1 by specifying productivity and rate of placement profiles for each operation of an activity. Examples of Chapter 6 exemplify the use of the two programs fully.

B-1 PROGRAM 1: OPERATION DURATION

This program calculates the duration of a specific operation. Since duration is not initially known, productivity and manpower data must be entered on a normalized time basis. The required steps of the program are as given in Section 5-7.1.

```
C
C       PROGRAM TO CALCULATE OPERATION DURATION
C       FOR KNOWN NORMALIZED PRODUCTIVITY AND
C            MANPOWER RESOURCE PROFILES
C
      DIMENSION PROD(100),X(100),R(3),CR(100),XB(100),C(3,3)
      DATA SX,SY,SX2,SX3,SX4,SXY,SX2Y/0.,0.,0.,0.,0.,0.,0./
      DATA IYN/'Y'/
C
      DO 10 I=1,2
      LU=I
      WRITE(LU,20)
   20 FORMAT(1X,/,1X,
     ^'*********************************************************',/,1
     ^'                OPERATION DURATION                      ',/,1X
     ^'*********************************************************')
   10 CONTINUE
C
      WRITE(1,30)
   30 FORMAT(1X,'ENTER OPERATION DESCRIPTION')
      READ(1,40)M1,M2,M3,M4,M5,M6,M7,M8,M9,M10
   40 FORMAT(10A4)
      WRITE(2,50)M1,M2,M3,M4,M5,M6,M7,M8,M9,M10
   50 FORMAT(1X,/,3X,'OPERATION-',10A4)
C
C        NORMALIZED PRODUCTIVITY CURVE
C        ENTER NUMBER OF DIVISIONS OPERATION IS DIVIDED
C        INTO AND THE AVERAGE PRODUCTIVITY OVER EACH DIVISION
C
C        PRODUCTIVITY AS (UNITS/MAN-HOUR)
C
      WRITE(1,60)
   60 FORMAT(1X,'ENTERING NORMALIZED PRODUCTIVITY CURVE')
C
      WRITE(1,55)
   55 FORMAT(1X,'ARE QUADRATIC PARAMETERS KNOWN?(Y/N)')
      READ(1,56)MANS
   56 FORMAT(A1)
      IF(MANS.EQ.IYN)GO TO 195
      WRITE(1,70)
   70 FORMAT(1X,/,1X,'OPERATION DURATION DIVIDED INTO 'N' EQUAL'
     ^'DIVISIONS ENTER N')
      READ(1,*)NDIVP
      SODP=100.0/NDIVP
      SODPL=0.0
      SODPH=SODP
C
      WRITE(2,85)
   85 FORMAT(1X,/,1X,10X,'PRODUCTIVITY VALUES ENTERED (UNITS/MAN
      DO 80 IBW=1,NDIVP
      WRITE(1,90)SODPL,SODPH
   90 FORMAT(1X,'ENTER AVERAGE PRODUCTIVITY FOR ',F6.2,'% TO',/,
     ^F6.2,'% OF OPERATION DURATION DURATION UNITS PER MANHR')
      READ(1,*)PROD(IBW)
      WRITE(2,86)PROD(IBW)
   86 FORMAT(12X,F10.3)
      X(IBW)=SODPL+SODP/2.0
```

```
      SODPL=SODPH
      SODPH=SODPH+SODP
   80 CONTINUE
C
C           CALCULATION OF BEST FIT QUADRATIC PARAMETERS
C                   USING NUMERICAL METHODS
C
      DO 100 IL=1,NDIVP
      SX=SX+X(IL)
      SY=SY+PROD(IL)
      SX2=SX2+X(IL)**2
      SX3=SX3+X(IL)**3
      SX4=SX4+X(IL)**4
      SXY=SXY+X(IL)*PROD(IL)
      SX2Y=SX2Y+X(IL)*X(IL)*PROD(IL)
  100 CONTINUE
C
      C(1,1)=NDIVP
      C(1,2)=SX
      C(1,3)=SX2
      C(2,1)=SX
      C(2,2)=SX2
      C(2,3)=SX3
      C(3,1)=SX2
      C(3,2)=SX3
      C(3,3)=SX4
      R(1)=SY
      R(2)=SXY
      R(3)=SX2Y
C
      LN=3
      LK=1
  110 CONTINUE
      TEMP=(1.0/C(LK,LK))
      LJ=LK
  120 CONTINUE
      C(LK,LJ)=C(LK,LJ)*TEMP
      IF(LJ.EQ.LN)GO TO 130
      LJ=LJ+1
      GO TO 120
  130 CONTINUE
      R(LK)=R(LK)*TEMP
      LJ=1
  140 CONTINUE
      IF(LK.EQ.LJ)GO TO 170
      TEMP=C(LJ,LK)
      LL=LK
  150 CONTINUE
      C(LJ,LL)=C(LJ,LL)-C(LK,LL)*TEMP
      IF(LL.EQ.LN)GO TO 160
      LL=LL+1
      GO TO 150
  160 CONTINUE
      R(LJ)=R(LJ)-R(LK)*TEMP
  170 CONTINUE
      IF(LJ.EQ.LN)GO TO 180
      LJ=LJ+1
```

```
      GO TO 140
  180 CONTINUE
      IF(LK.EQ.LN)GO TO 190
      LK=LK+1
      GO TO 110
  190 CONTINUE
C
      IF(MANS.NE.IYN)GO TO 197
  195 CONTINUE
      WRITE(1,196)
  196 FORMAT(1X,/,1X,'ENTER QUADRATIC PARAMETERS R(1),R(2),R(3)'
      READ(1,*)R(1),R(2),R(3)
  197 CONTINUE
C
C
      DO 200 J=1,2
      LU=J
      WRITE(LU,210)R(1),R(2),R(3)
  210 FORMAT(1X,12X,'BEST FIT QUADRATIC GIVES',/,1X,12X,
     ^'PRODUCTIVITY=',F10.6,'+',F10.6,'T+',F10.6,'T**2',/,
     ^1X,12X,'WHERE 'T' IS %.OF OPERATION DURATION').
  200 CONTINUE
C
C           ENTER NORMALIZED MANPOWER
C        ENTER NUMBER OF DIVISIONS OPERATION DURATION IS
C        DIVIDED INTO AND THE AVERAGE MANPOWER WORKING
C              DURING EACH DIVISION
C
C       *****************  NOTE  *********************
C       IF SELECT TO ENTER PARAMETERS DIRECTLY MUST
C       STILL ENTER NORMALIZED MANPOWER DATA
C
      WRITE(1,215)
  215 FORMAT(1X,/,1X,'ENTERING NORMALIZED MANPOWER PROFILE)')
C
      WRITE(1,216)
  216 FORMAT(1X,'ARE THE BETA PARAMETERS KNOWN?(Y/N)')
      READ(1,217)LANS
  217 FORMAT(A1)
      IF(LANS.EQ.IYN)GO TO 255
C
      WRITE(1,220)
  220 FORMAT(1X,'DIVIDE OPERATION DURATION INTO 'N' EQUAL',/,1X,
     ^'DIVISIONS ENTER N')
      READ(1,*)NDIVL
      SOIL=100./NDIVL
      SOILL=0.0
      SOILH=SOIL
      RTOT=0.0
C
      WRITE(2,221)
  221 FORMAT(1X,/,11X,'MANPOWER VALUES ENTERED(MEN)')
C
      DO 230 IBX=1,NDIVL
      WRITE(1,240)SOILL,SOILH
  240 FORMAT(1X,'ENTER AVERAGE MANPOWER FOR ',F6.2,'% TO',/,1X,
     ^F6.2,'% OF OPERATION DURATION')
```

```
      READ(1,*)CQ(IBX)
      WRITE(2,241)CQ(IBX)
  241 FORMAT(12X,F10.3)
      XB(IBX)=SOILL+SOIL/2.0
      XB(IBX)=(SOILL+SOIL/2.0)/100.
      SOILL=SOILH
      SOILH=SOILH+SOIL
      RTOT=RTOT+CQ(IBX)
  230 CONTINUE
C
C          CALCULATION OF BEST FIT BETA PARAMETERS
C                  USING NUMERICAL METHODS
C
C
      SUMY=RTOT
      SAVG=0.0
      DO 245 JD=1,NDIVL
      SAC=XB(JD)*CQ(JD)
      SAVG=SAVG+SAC
  245 CONTINUE
      SAVG=SAVG/SUMY
C
      SVAR=0.0
      DO 250 KD=1,NDIVL
      SVC=(ABS(XB(KD)-SAVG)**2.0)*CQ(KD)
      SVAR=SVAR+SVC
  250 CONTINUE
      SVAR=SVAR/SUMY
C
      ZD=(((SAVG)*(1.0-SAVG))/SVAR)-1.0
      PD=SAVG*ZD
      SD=(1.0-SAVG)*ZD
      QD=SD+PD
C
      IF(LANS.NE.IYN)GO TO 257
  255 CONTINUE
      WRITE(1,256)
  256 FORMAT(1X,'ENTER BETA PARAMETERS P AND Q')
      READ(1,*)PD,QD
      WRITE(1,231)
  231 FORMAT(1X,'DIVIDE OPERATION INTO 'N' EQUAL',/,1X,
     *'DIVISIONS,ENTER N')
      READ(1,*)NDIVL
      SOIL=100./NDIVL
      SOILL=0.0
      SOILH=SOIL
      RTOT=0.0
      WRITE(2,232)
  232 FORMAT(1X,/,11X,'MANPOWER VALUES ENTERED (MEN)')
      DO 233 IBXX=1,NDIVL
      WRITE(1,234)SOILL,SOILH
  234 FORMAT(1X,'ENTER AVERAGE MANPOWER FOR',F6.2,' % TO ',/,1X
     *F6.2,' % OF OPERATION DURATION')
      READ(1,*)CQ(IBXX)
      WRITE(2,235)CQ(IBXX)
  235 FORMAT(12X,F10.3)
      SOILL=SOILH
```

```
      SOILH=SOILH+SOIL
      RTOT=RTOT+CQ(IBXX)
  233 CONTINUE
  257 CONTINUE
      DO 259 LU=1,2
      WRITE(LU,260)PD,QD
  260 FORMAT(1X,
     ^'THE BEST FIT BETA PARAMETERS FOR MANPOWER PROFILE ARE',/,
     ^'P=',F8.4,/,11X,'Q=',F8.4)
  259 CONTINUE
C
      QDP=QD-PD
      CALL GMMA(PD,PG,PE)
      CALL GMMA(QD,QG,QE)
      CALL GMMA(QDP,QPG,QPE)
      BI=QG/(PG*QPG)
C
C  *****************************************************
C
      TT=50.0
      DO 261 IJZ=1,10
      XH=((IJZ/10.0)*TT)/TT-0.05
      ZMAN=BI*XH**(PD-1)*(1-XH)**(QD-PD-1)
      ZMAN=(RTOT/NDIVL)*ZMAN
      WRITE(1,262)ZMAN
  262 FORMAT(1X,'MANPOWER IS ',F5.1)
  261 CONTINUE
C
C  *********************************************************
C
C
C        UNIT TIME COMPOSITION
C
      WRITE(1,270)
  270 FORMAT(1X,'ENTER DAYS PER WEEK WORKED')
      READ(1,*)DPW
C
      WRITE(1,280)
  280 FORMAT(1X,'ENTER HOURS WORKED PER DAY')
      READ(1,*)HPD
C
      HPW=DPW*HPD
C
C         TOTAL WORK UNITS
C
      WRITE(1,290)
  290 FORMAT(1X,/,1X,'ENTER TOTAL WORK UNITS')
      READ(1,*)WU
C
C        CALCULATION OF DURATION
C
      WRITE(1,300)
  300 FORMAT(1X,/,1X,'ENTER DURATION ESTIMATE ON HIGH SIDE')
      READ(1,*)XO
      WRITE(1,310)
  310 FORMAT(1X,'ENTER DURATION ESTIMATE ON LOW SIDE')
      READ(1,*)XOO
```

```
C
      D=XO-XOO
      XT=XO
C
      CALL BINT(XOO,BI,PD,QD,R,HPD,DPW,RTOT,NDIVL,FOLD,PQ
      WRITE(1,9050)FOLD
 9050 FORMAT(1X,'FOLD =',F10.2)
      FOLD=FOLD-WU
      WRITE(1,9060)
 9060 FORMAT(1X,'CHECK 5')
C
  320 CONTINUE
      CALL BINT(XT,BI,PD,QD,R,HPD,DPW,RTOT,NDIVL,FNEW,PQQ
      FNEW=FNEW-WU
C
      D=(-FNEW)/((FNEW-FOLD)/D)
      XT=XT+D
      EPS=.1
      ABD=ABS(D)
      IF(ABD.GE.EPS)GO TO 320
C
      DO 330 KE=1,2
      LU=KE
      WRITE(LU,340)XT
  340 FORMAT(1X,/,1X,'OPERATION DURATION IS ',F7.2,' WEEK
      WRITE(LU,345)PQQ,QQQ
  345 FORMAT(1X,/,1X,
     ^'***********************************************
     ^'  THE BEST FIT BETA PARAMETERS FOR THE RATE OF    '
     ^'           QUANTITY PLACEMENT ARE',/,11X,
     ^'P=',F8.4,/,11X,'Q=',F8.4,/,1X,
     ^'***********************************************
  330 CONTINUE
      STOP
      END

 R04-00      MAINPROG     .MAIN      26/11/82  16:26:32  TAB
ER:    20 LINES/1321 BYTES     STACK SPACE: 193 WORDS
ON FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
C
C
      SUBROUTINE BINT(DUR,BI,PD,QD,R,HPD,DPW,
     *RTOT,NDIVL,RES,PQQ,QQQ)
      DIMENSION R(3),TMEA(2000),ARQUA(2000)
C
C     FIND TOTAL MANPOWER FOR GIVEN DURATION
C
      TOTMAN=0.0
      DCAL=DUR*DPW
      DO 346 JAB=1,DCAL
      XSTA=JAB-0.5
      XSTAP=XSTA/DCAL
      AA1=RTOT/NDIVL
      AA2=XSTAP**(PD-1)
      AA3=(1.0-XSTAP)**(QD-PD-1)
      AREAOM=AA1*AA2*AA3*BI
      TOTMAN=TOTMAN+AREAOM
  346 CONTINUE
      WRITE(1,9010)
 9010 FORMAT(1X,'CHECK 2')
C
C       CALCULATE AREA UNDER THE L(T)P(T) CURVE
C                  DAY BY DAY BASIS
C
      TOTQUA=0.0
      DO 510 CAB=1,DCAL
      MAB=INT(CAB)
      TMEA(MAB)=CAB-0.5
      TMEAP=TMEA(MAB)/DCAL
C        MANPOWER CALCULATION DAY CAB
      S1=TOTMAN/DCAL
      S2=TMEAP**(PD-1)
      S3=(1.0-TMEAP)**(QD-PD-1)
C        TOTAL MAN-HOURS PER DAY
      ARMAN=S1*S2*S3*BI*HPD
C        PRODUCTIVITY DAY CAB
      ARPR=R(1)+R(2)*TMEAP+R(3)*TMEAP**2
C        QUANTITY PLACED DAY CAB
      ARQUA(MAB)=ARMAN*ARPR
C        QUANTITY SUMMATION
      TOTQUA=TOTQUA+ARQUA(MAB)
      TMEA(MAB)=TMEA(MAB)/DCAL
  510 CONTINUE
      WRITE(1,9020)
 9020 FORMAT(1X,'CHECK 3')
      RES=TOTQUA
C
C       CALCULATION OF BEST FIT BETA PARAMETERS
C
      SUMZ=TOTQUA
      SAVG1=0.0
      DO 400 JJD=1,DCAL
      SAC1=TMEA(JJD)*ARQUA(JJD)
      SAVG1=SAVG1+SAC1
  400 CONTINUE
      SAVG1=SAVG1/SUMZ
```

```
C
      SVAR1=0.0
      DO 410 KKD=1,DCAL
      SVC1=(ABS(TMEA(KKD)-SAVG1)**2.0)*ARQUA(KKD)
      SVAR1=SVAR1+SVC1
  410 CONTINUE
      SVAR1=SVAR1/SUMZ
C
      ZD1=(((SAVG1)*(1.0-SAVG1))/SVAR1)-1.0
      PQQ=SAVG1*ZD1
      SQQ=(1.0-SAVG1)*ZD1
      QQQ=SQQ+PQQ
      WRITE(1,9040)
 9040 FORMAT(1X,'CHECK 4')
      RETURN
      END

D  R04-00      SUBROUTINE  BINT       26/11/82  16:26:34  TABLE SPAC
FER:   20 LINES/1321 BYTES     STACK SPACE: 193 WORDS
ION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
C
C
C
C
      SUBROUTINE GMMA(XX,GX,IER)
      IF(XX-57.)1020,1020,1025
 1025 IER=2
      GX=1.E75
      RETURN
 1020 XA=XX
      ERR=1.0E-6
      IER=0
      GX=1.0
      IF(XA-2.0)1030,1030,1035
 1040 IF(XA-2.0)1045,1045,1035
 1035 XA=XA-1.0
      GX=GX*XA
      GO TO 1040
 1030 IF(XA-1.0)1050,1055,1045
 1050 IF(XA-ERR)1060,1060,1065
 1060 Y=FLOAT(INT(XA))-XA
      IF(ABS(Y)-ERR)1070,1070,1075
 1075 IF(1.0-Y-ERR)1070,1070,1080
 1080 IF(XA-1.0)1065,1065,1045
 1065 GX=GX/XA
      XA=XA+1.0
      GO TO 1080
 1045 Y=XA-1.0
      GY=1.0+Y*(-0.5771017+Y*(0.9858540+Y*(-0.8764218
     ^+Y*(0.8328212+Y*(-0.5684729+Y*(0.2548205
     ^+Y*(-0.05149930)))))))
      GX=GX*GY
 1055 RETURN
 1070 IER=1
      RETURN
      END

D  R04-00      SUBROUTINE  GMMA       26/11/82  16:26:35  TABLE SPAC
FER:   20 LINES/1321 BYTES    STACK SPACE: 297 WORDS
ION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

B-2 PROGRAM 2: ACTIVITY MODEL

Operations duration must be known for use of this program. For each operation of the activity a labor productivity and rate of placement profile must be entered. Costs associated with an operation and their respective timings must also be entered. The required manpower profile for the activity and each operation along with the activity cash flow and total constant dollar cost of the activity are calculated and output. Section 5-7 lists the steps required for each operation of this activity.

```
      C
      C        **************************************************
      C
      C                        ACTIVITY MODEL
      C
      C        **************************************************
      C
      C          AN ACTIVITY IS COMPOSED OF A NUMBER OF OPERATIONS
      C          AND EACH OPERATION IS COMPOSED OF A NUMBER OF
      C          WORK SHIFTS
      C
      C          A CONSTANT DOLLAR CASH FLOW IS ESTABLISHED FOR
      C          FOR EACH WORK SHIFT OF AN OPERATION
      C
      C          THE SUMMATION OF THE CASH FLOWS FOR EACH SHIFT
      C          GIVES THE OPERATION CASH FLOW
      C
      C          THE SUMMATION OF THE CASH FLOWS FOR EACH OPERATION
      C          IN AN ACTIVITY GIVES THE ACTIVITY CONSTANT DOLLAR
      C          CASH FLOW
      C
      C          *****************VARIABLE LIST**********************
      C          OP1           ARRAY FOR OPERATION CASH FLOWS
      C          ACT           ARRAY FOR ACTIVITY CASH FLOWS
      C          PROD          ARRAY FOR PRODUCTIVITY RATE INPUTS
      C          R             QUADRATIC PARAMETERS
      C          PD,QD         BETA CURVW PARAMETERS
      C          CQ            ARRAY FOR CUMULATIVE PLACEMENT INPUTS
      C          QMANP         ARRAY FOR MANPOWER
      C          MAXA          MAXIMUM ACTIVITY CASH FLOW
      C          NUMO          NUMBER OF OPERATIONS IN ACTIVITY
      C          IODW          OPERATION DURATION
      C          IOID          OPERATION INSTALLATION DURATION
      C          IOSA          TIME OF OPERATION START IN ACTIVITY
      C          NUMS          NUMBER OF OPERATION WORK SHIFTS
      C          IWP           PRODUCTIVITY ENTERED EVERY 'IWP' WEEKS
      C          OQ            OPERATION TOTAL WORK QUANTITY
      C          NDIV          INSTALLATION DURATION DIVIDED INTO 'NDIV'
      C          POTQ          PERCENT CUMULATIVE PLACEMENT
      C          DPW           DAYS PER WEEK WORKED
      C          RHPD          REGULAR HOURS WORKED PER DAY
      C          PHPD          OVERTIME   "     "     "   "
      C          RWR           REGULAR WAGE RATE
      C          PWR           OVERTIME   "   "
      C          MP            TIME OF LUMP SUM COST
      C          AMTP          AMOUNT OF LUMP SUM COST
      C          MPA           TIME OF ACTIVITY LUMP SUMS
      C          AMTPA         AMOUNT OF ACTIVITY LUMP SUMS
      C          RR            UNIFORM FLOW AMOUNT
      C          ISE           TIME OF START OF UNIFORM FLOW
      C          INW           WEEKS UNIFORM FLOW OCCURS
      C          RRA           ACTIVITY UNIFORM FLOW
      C          ISEA          TIME OF START OF ACTIVITY UNIFORM FLOW
      C          INWA          WEEKS OF ACTIVITY UNIFORM FLOW
      C          PDD           PRODUCTIVITY FUNCTION
      C          QP            RATE OF PLACEMENT FUNCTION
      C          QMAN          MAN POWER
```

```
: LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002          **
  C          HUM           LABOR COST
  C          DPU.          DOLLAR COST PER UNIT QUANTITY PLACED
  C          SDPU          SUM OF UNIT COSTS
  C          ZUC           TOTAL COST OF UNIT COSTS
  C
        DIMENSION DP1(150),ACT(200),
       ^PROD(150),X(150),C(3,3),R(3),
       ^CQ(150),XB(150),QMANP(200),
       ^QMANO(100)
        CHARACTER*1 JPROD(100)
        DATA IYN/'N'/
        DATA(JPROD(LKZ),LKZ=1,100)/100*' '/
        DOUBLE PRECISION TEMP,C,R
        MAXA=0
  C
        WRITE(2,12)
     12 FORMAT(1X,/,1X,/,1X,
       ^'*****************************************************',/,1
       ^'                                                     ',/,1
       ^'                  ACTIVITY MODEL                     ',/,1
       ^'                                                     ',/,1
       ^'*****************************************************')
        WRITE(1,5)
      5 FORMAT(20X,'*****ACTIVITY MODEL*****',/,1X,/,1X,
       ^'ACTIVITY IS COMPOSED OF OPERATIONS')
  C          ACTIVITY DESCRIPTION
        WRITE(1,700)
    700 FORMAT(1X,/,1X,'ENTER ACTIVITY DESCRIPTION')
        READ(1,701)NA1,NA2,NA3,NA4,NA5,NA6,NA7,NA8,NA9,NA10
    701 FORMAT(10A4)
        WRITE(2,702)NA1,NA2,NA3,NA4,NA5,NA6,NA7,NA8,NA9,NA10
    702 FORMAT(1X,/,1X,'ACTIVITY DESCRIPTION-',10A4)
  C
  C            LUMP SUM COSTS OF ACTIVITY
  C
        WRITE(2,905)
    905 FORMAT(1X,/,1X,12X,'ACTIVITY LUMP SUMS',/,1X,12X,
       ^'WEEK          AMOUNT            DESCRIPTION')
    935 CONTINUE
        WRITE(1,900)
    900 FORMAT(1X,/,1X,'LUMP SUM COSTS OF ACTIVITY',/,1X,
       ^'ENTER WEEK OF LUMP SUM AND AMOUNT')
        READ(1,*)MPA,AMTPA
        WRITE(1,910)
    910 FORMAT(1X,/,1X,'ENTER DESCRIPTION')
        READ(1,915)LZ1,LZ2,LZ3,LZ4,LZ5
    915 FORMAT(5A4)
        WRITE(2,920)MPA,AMTPA,LZ1,LZ2,LZ3,LZ4,LZ5
    920 FORMAT(1X,12X,I3,8X,'$',F12.2,6X,5A4)
        ACT(MPA)=ACT(MPA)+AMTPA
        WRITE(1,925)
    925 FORMAT(1X,/,1X,'ENTER ANOTHER LUMP SUM COST?(Y/N)')
        READ(1,930)IAPA
    930 FORMAT(A1)
        IF(IAPA.NE.IYN)GO TO 935
  C
  C          UNIFORM CASH FLOWS OF ACTIVITY
```

```
C
      WRITE(2,950)
  950 FORMAT(1X,/,1X,12X,'UNIFORM  COSTS OF ACTIVITY',/,1X,12X,
     ~'WEEKLY  RATE      WEEK START      WEEKS          DESCRIPTION
  985 CONTINUE .
      WRITE(1,955)
  955 FORMAT(1X,/,1X,'UNIFORM COSTS OF ACTIVITY',/,1X,
     ~'ENTER WEEKLY RATE,WEEK FIRST EMPLOYED AND WEEKS USED')
      READ(1,*)RRA,ISEA,INWA
      WRITE(1,960)
  960 FORMAT(1X,/,1X,'ENTER COST DESCRIPTION')
      READ(1,965)KZ1,KZ2,KZ3,KZ4,KZ5
  965 FORMAT(5A4)
      WRITE(2,970)RRA,ISEA,INWA,KZ1,KZ2,KZ3,KZ4,KZ5
  970 FORMAT(1X,12X,'$',F10.2,8X,I3,11X,I3,10X,5A4)
      IWEA=ISEA+INWA-1
      DO 975 I3Z=ISEA,IWEA
      ACT(I3Z)=ACT(I3Z)+RRA
  975 CONTINUE
      WRITE(1,980)
  980 FORMAT(1X,/,1X,'ANOTHER ACTIVITY UNIFORM COST?(Y/N)')
      READ(1,981)IAEA
  981 FORMAT(A1)
      IF(IAEA.NE.IYN)GO TO 985
C
C         NUMBER OF OPERATIONS IN ACTIVITY
C
      WRITE(1,10)
   10 FORMAT(1X,'NUMBER  OF OPERATIONS IN THE ACTIVITY')
      READ(1,*)NUMO
C
      WRITE(2,11)NUMO
   11 FORMAT(1X,/,3X,'NUMBER OF OPERATIONS IN ACTIVITY=',I2)
C
C
      DO 15 I2=1,NUMO
C
C
      WRITE(1,20)I2
   20 FORMAT(1X,/,20X,'*****OPERATION ',I2,'*****')
C       OPERATION DESCRIPTION
      WRITE(1,21)
   21 FORMAT(1X,'ENTER OPERATION DESCRIPTION')
      READ(1,22)MA1,MA2,MA3,MA4,MA5,MA6,MA7,MA8,MA9,MA10
   22 FORMAT(10A4)
C
C        OPERATION DURATION
C
      WRITE(1,35)
   35 FORMAT(1X,'ENTER OPERATION DURATION IN WEEKS')
      READ(1,*)IODW
C
C         OPERATION INSTALLATION PHASE DURATION
C
      IOID=IODW
C
C           ACTIVITY TIME OPERATION STARTS
```

```
C
      WRITE(1,140)
  140 FORMAT(1X,'WEEK OPERATION STARTS IN ACTIVITY')
      READ(1,*)IOSA
C
C          ' NUMBER OF WORK SHIFTS IN OPERATION
C
      WRITE(1,41)I2
   41 FORMAT(1X,/,1X,'FOR OPERATION ',I2,' ENTER NUMBER ',/,1X,
     ^'OF SHIFTS')
      READ(1,*)NUMS
C
      WRITE(2,23)I2,MA1,MA2,MA3,MA4,MA5,MA6,MA7,MA8,MA9,MA10
   23 FORMAT(1X,/,3X,'** OPERATION-',I2,1X,10A4)
      WRITE(2,44)I2,NUMS
   44 FORMAT(5X,'OPERATION ',I2,' HAS ',I2,' SHIFTS')
      WRITE(2,46)IODW
   46 FORMAT(8X,'OVERALL OPERATION DURATION ',I3,' WEEKS')
      WRITE(2,141)IOSA
  141 FORMAT(8X,'OPERATION STARTS IN WEEK ',I3,' OF ACTIVITY')
C
      DO 42 KJK=1,NUMS
C
      DO 16 JKJ=1,150
      OP1(JKJ)=0.0
   16 CONTINUE
C
      WRITE(2,45)KJK
   45 FORMAT(1X,/,1X,10X,'SHIFT ',I2)
      WRITE(1,43)I2,KJK
   43 FORMAT(1X,/,10X,'*****OPERATION ',I2,'*****SHIFT ',I2,'***
C
C
C           PRODUCTIVITY PACKAGE
C           BEST FIT QUADRATIC EQUATION USED AS MODEL
C
C            ARE PARAMETERS KNOWN
      WRITE(1,53)
   53 FORMAT(1X,/,1X,'PRODUCTIVITY MODELED BY QUADRATIC',/,1X,
     ^'ARE PARAMETERS KNOWN?(Y/N)')
      READ(1,540)IPAN
  540 FORMAT(A1)
      IF(IPAN.NE.IYN)GO TO 401
C
C           PARAMETERS NOT KNOWN ENTER INPUT PRODUCTIVITIES
C
      WRITE(1,50)
   50 FORMAT(1X,'PRODUCTIVITY ENTERED EVERY "!" WEEKS',/,1X,
     ^'WHERE "!" IS AN INTEGER, ENTER "!"')
      READ(1,*)IWP
C
      NUM=1
      ICT=1
      ICT2=IWP
C
C           ENTERING OF PRODUCTIVITY VALUES
C
```

```
      WRITE(2,49)
   49 FORMAT(1X,/,1X,12X,'PRODUCTIVITY VALUES ENTERED',/,1X,12X,
     *' WEEK   PRODUCTIVITY RATE (UNITS/MAN-HOUR)')
C
   54 CONTINUE
      WRITE(1,52)ICT,ICT2
   52 FORMAT(1X,'ENTER PRODUCTIVITY FOR WEEK ',I3,'-',I3)
      X(NUM)=ICT2-(ICT2-(ICT-1))/2
      READ(1,*)PROD(NUM)
      WRITE(2,51)ICT,ICT2,PROD(NUM)
   51 FORMAT(1X,12X,I3,'-',I3,14X,F8.3)
      IF(ICT2.EQ.IOID)GO TO 56
      ICT=ICT+IWP
      ICT2=ICT2+IWP
      IF(ICT2.GT.IOID)ICT2=IOID
      NUM=NUM+1
      GO TO 54
C
C         NUMERICAL METHOD-GAUSS JORDAN AND LEAST SQUARES
C         CURVE FITTING OF DISCRETE POINTS
C
   56 CONTINUE
      SX=0.
      SX2=0.
      SX3=0.
      SX4=0.
      SY=0.
      SXY=0.
      SX2Y=0.
C
      DO 57 IL=1,NUM
      SX=SX+X(IL)
      SY=SY+PROD(IL)
      SX2=SX2+X(IL)**2
      SX3=SX3+X(IL)**3
      SX4=SX4+X(IL)**4
      SXY=SXY+X(IL)*PROD(IL)
      SX2Y=SX2Y+X(IL)*X(IL)*PROD(IL)
   57 CONTINUE
C
C         MATRIX VALUES
C
      C(1,1)=NUM
      C(1,2)=SX
      C(1,3)=SX2
      C(2,1)=SX
      C(2,2)=SX2
      C(2,3)=SX3
      C(3,1)=SX2
      C(3,2)=SX3
      C(3,3)=SX4
      R(1)=SY
      R(2)=SXY
      R(3)=SX2Y
C
C       ARRAY SIZE IS THREE
C
```

```
      LN=3
      LK=1
  335 CONTINUE
      TEMP=1.0/C(LK,LK)
      LJ=LK
  340 CONTINUE
      C(LK,LJ)=C(LK,LJ)*TEMP
      IF(LJ.EQ.LN)GO TO 350
      LJ=LJ+1
      GO TO 340
  350 CONTINUE
      R(LK)=R(LK)*TEMP
      LJ=1
  355 CONTINUE
      IF(LK.EQ.LJ)GO TO 380
      TEMP=C(LJ,LK)
      LL=LK
  360 CONTINUE
      C(LJ,LL)=C(LJ,LL)-C(LK,LL)*TEMP
      IF(LL.EQ.LN)GO TO 370
      LL=LL+1
      GO TO 360
  370 CONTINUE
      R(LJ)=R(LJ)-R(LK)*TEMP
  380 CONTINUE
      IF(LJ.EQ.LN)GO TO 390
      LJ=LJ+1
      GO TO 355
  390 CONTINUE
      IF(LK.EQ.LN)GO TO 400
      LK=LK+1
      GO TO 335
  400 CONTINUE
C
C        PARAMETERS ARE KNOWN
C
      GO TO 403
  401 CONTINUE
      WRITE(1,402)
  402 FORMAT(1X,'ENTER PARAMETER VALUES R(1),R(2),R(3)')
      READ(1,*)R(1),R(2),R(3)
  403 CONTINUE
C
      WRITE(1,410)
  410 FORMAT(1X,'THE SOLUTION VECTOR IS!')
      WRITE(1,420)R(1),R(2),R(3)
  420 FORMAT(1X,'PRODUCTIVITY=',F10.6,'+',F10.6,'T+',F10.6,'T**2
      WRITE(1,430)
  430 FORMAT(1X,'WHERE 'T' IS TIME IN WEEKS')
      WRITE(2,431)R(1),R(2),R(3)
  431 FORMAT(1X,12X,'BEST FIT QUADRATIC GIVES',/,1X,12X,
     ^'PRODUCTIVITY=',F10.6,'+',F10.6,'T+',F10.6,'T**2',/,
     ^1X,12X,'WHERE 'T' IS TIME IN WEEKS')
C
C        TOTAL NUMBER OF WORK UNITS
C
      WRITE(1,60)
```

```
: LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002          **
     60 FORMAT(1X,/,1X,'ENTER TOTAL NUMBER OF WORK UNITS')
        READ(1,*)DQ
C
        WRITE(2,58)DQ
     58 FORMAT(1X,/,1X,12X,'TOTAL WORK UNITS ',F12.2)
C
C         WEEKLY PLACEMENT RATE
C
C
C         MODELING OF OPERATION CUMULATIVE 'S-CURVE'
C         BY BEST FIT BETA DISTRIBUTION
C
C         ARE PARAMETERS KNOWN
        WRITE(1,59)
     59 FORMAT(1X,/,1X,'S-CURVE MODELED BY BETA CURVE',/,1X,
       ^'ARE PARAMETERS KNOWN?(Y/N)')
        READ(1,64)IBYN
     64 FORMAT(A1)
        IF(IBYN.NE.IYN)GO TO 822
C
C         PARAMETERS NOT KNOWN
C
C          MUST INPUT VALUES OF CUMULATIVE QUANTITY CURVE
C
        WRITE(1,61)
     61 FORMAT(1X,'INSTALLATION DURATION MUST BE DIVIDED',/,1X,
       ^'INTO 'N' EQUAL DIVISIONS,EACH DIVISION REQUIRES',/,1X,
       ^'AN INPUT,ENTER N')
        READ(1,*)NDIV
C
C           SIZE OF INTERVAL
C
        SOI=(IOID*1.0)/(NDIV*1.0)
C
        WRITE(2,66)
     66 FORMAT(1X,/,1X,12X,'PLACEMENT VALUES ENTERED',/,1X,12X,
       ^'% INSTALLATION DURATION      % PLACED')
C
        DO 63 JCT=1,NDIV
        POID=((JCT*SOI)/(IOID*1.0))*100.00
        WRITE(1,62)POID
     62 FORMAT(1X,'ENTER % OF TOTAL QUANTITY PLACED AT',/,1X,
       ^'END OF ',F6.2,'% OF OPERATION INSTALLATION DURATION')
        READ(1,*)POTQ
        WRITE(2,67)POID,POTQ
     67 FORMAT(1X,12X,10X,F6.2,14X,F6.2)
        CQ(JCT)=(POTQ/100.0)*DQ
        XB(JCT)=(SOI/2)+(JCT-1)*SOI
        XB(JCT)=XB(JCT)/IOID
     63 CONTINUE
C
C          DATA MUST BE CONVERTED TO RATE OF PLACEMENT
C          TO FACILITATE PARAMETER CALCULATION
C
        LNM=NDIV
        NM1=NDIV-1
        DO 780 LNN=1,NM1
```

```
      LNM1=LNM-1
      CQ(LNM)=CQ(LNM)-CQ(LNM1)
      LNM=NDIV-LNN
  780 CONTINUE
C
C
C        CALCULATION OF SAMPLE AVERAGE
C
      SUMY=OQ
      SAVG=0.0
      DO 800 JD=1,NDIV
      SAC=XB(JD)*CQ(JD)
      SAVG=SAVG+SAC
  800 CONTINUE
      SAVG=SAVG/SUMY
C
C        CALCULATION OF SAMPLE VARIANCE
C
      SVAR=0.0
      DO 810 KD=1,NDIV
      SVC=(ABS(XB(KD)-SAVG)**2.0)*CQ(KD)
      SVAR=SVAR+SVC
  810 CONTINUE
      SVAR=SVAR/SUMY
C
C        CALCULATION OF PARAMETERS
C
      ZD=(((SAVG)*(1.0-SAVG))/SVAR)-1.0
      PD=SAVG*ZD
      SD=(1.0-SAVG)*ZD
      QD=SD+PD
      WRITE(1,820)PD,QD
  820 FORMAT(1X,'THE BEST FIT BETA PARAMETERS ARE',/,11X,
     ^'P=',F8.4,/,11X,'Q=',F8.4)
C
C        CALCULATION OF BI
C
      GO TO 821
  822 CONTINUE
      WRITE(1,823)
  823 FORMAT(1X,'ENTER BETA PARAMETERS P&Q')
      READ(1,*)PD,QD
  821 CONTINUE
C
C
      QDP=QD-PD
      CALL GMMA(PD,PG,PE)
      CALL GMMA(QD,QG,QE)
      CALL GMMA(QDP,QPG,QPE)
      BI=QG/(PG*QPG)
      WRITE(2,71)PD,QD
   71 FORMAT(1X,12X,'RATE OF PLACEMENT GIVEN BY BEST FIT BETA CU
     ^1X,12X,'WITH BETA PARAMETERS',/,15X,'P=',F8.4,/,15X,'Q=',F
C
C        WORKED DAYS PER WEEK
C
      WRITE(1,70)
```

```
   70 FORMAT(1X,'ENTER DAYS PER WEEK WORKED')
      READ(1,*)DPW
C
C        REGULAR WORKED HOURS PER DAY
C
      WRITE(1,75)
   75 FORMAT(1X,'ENTER REGULAR HOURS WORKED PER DAY')
      READ(1,*)RHPD
C
C        OVERTIME WORKED HOURS PER DAY
C
      WRITE(1,102)
  102 FORMAT(1X,'ENTER OVERTIME HOURS WORKED PER DAY')
      READ(1,*)PHPD
C
C        CALCULATE HOURS PER WEEK
C
      RHPW=RHPD*DPW
      PHPW=PHPD*DPW
C
C          UNIT LABOR COST FOR REGULAR TIME
C
      WRITE(1,76)
   76 FORMAT(1X,'ENTER REGULAR HOURLY WAGE RATE')
      READ(1,*)RWR
C
C           UNIT LABOR COST FOR OVERTIME TIME
C
      WRITE(1,103)
  103 FORMAT(1X,'ENTER OVERTIME HOURLY WAGE RATE')
      READ(1,*)PWR
C
      WRITE(2,77)DPW,RHPD,PHPD,RWR,PWR
   77 FORMAT(1X,/,1X,12X,'DAYS PER WEEK WORKED ',F4.2,/,
     ^1X,12X,'REGULAR HOURS WORKED PER DAY ',F5.2,/,
     ^1X,12X,'OVERTIME HOURS WORKED PER DAY ',F5.2,/,
     ^1X,12X,'REGULAR HOURLY WAGE RATE $',F6.2,'/MAN-HOUR',/,
     ^1X,12X,'OVERTIME HOURLY WAGE RATE $',F6.2,'/MAN-HOUR')
C
C          PROCUREMENTS ENTERED FOR SHIFT
C          MAY ALSO INCLUDE ANY OTHER LUMP SUM CASH FLOWS
C
      WRITE(2,81)
   81 FORMAT(1X,/,1X,12X,'LUMP SUM COSTS',/,
     ^1X,12X,'WEEK        AMOUNT           DESCRIPTION')
   95 CONTINUE
      WRITE(1,80)
   80 FORMAT(1X,'ENTER WEEK OF LUMP SUM COST & AMOUNT')
      READ(1,*)MP,AMTP
      WRITE(1,703)
  703 FORMAT(1X,/,1X,'ENTER COST DESCRIPTION')
      READ(1,704)LA1,LA2,LA3,LA4,LA5
  704 FORMAT(5A4)
      WRITE(2,82)MP,AMTP,LA1,LA2,LA3,LA4,LA5
   82 FORMAT(1X,12X,I3,8X,'$',F12.2,6X,5A4)
      OP1(MP)=OP1(MP)+AMTP
      WRITE(1,85)
```

```
   85 FORMAT(1X,'ENTER ANOTHER LUMP SUM COST?(Y/N)')
      READ(1,90)IAP
   90 FORMAT(A1)
      IF(IAP.NE.IYN)GO TO 95
C
C        EQUIPMENT COST DEPENDENT ON RATE AND TIME REQUIRED
C        ENTER RENTAL RATE AND TIME REQUIRED
C        MAY ALSO BE USED FOR OTHER UNIFORM CASH FLOWS
C
      WRITE(2,121)
  121 FORMAT(1X,/,1X,12X,'UNIFORM COST',/,1X,12X,
     ^'WEEKLY RATE     WEEK START     WEEKS          DESCRIPTION
  130 CONTINUE
      WRITE(1,110)
  110 FORMAT(1X,'UNIFORM COST WEEKLY RATE,WEEK FIRST EMPLOYED',/
     ^1X,'AND NUMBER OF WEEKS EMPLOYED')
      READ(1,*)RR,ISE,INW
      WRITE(1,705)
  705 FORMAT(1X,/,1X,'ENTER COST DESCRIPTION')
      READ(1,706)KA1,KA2,KA3,KA4,KA5
  706 FORMAT(5A4)
      WRITE(2,122)RR,ISE,INW,KA1,KA2,KA3,KA4,KA5
  122 FORMAT(1X,12X,'$',F10.2,8X,I3,11X,I3,10X,5A4)
      IWE=ISE+INW-1
      DO 115 I3=ISE,IWE
      OP1(I3)=OP1(I3)+RR
  115 CONTINUE
C
      WRITE(1,120)
  120 FORMAT(1X,'ANOTHER UNIFORM COST?(Y/N)')
      READ(1,125)IAE
  125 FORMAT(A1)
      IF(IAE.NE.IYN)GO TO 130
C
C       OPERATION COSTS THAT ARE FUNCTIONS OF THE RATE OF
C       PLACEMENT OF WORK UNITS.ENTER COSTS PER UNIT PLACED
C
      SDPU=0.0
      WRITE(2,600)
  600 FORMAT(1X,/,1X,12X,'COSTS PER UNIT PLACED',/,1X,12X,
     ^'COST/UNIT          DESCRIPTION')
  635 CONTINUE
      WRITE(1,605)
  605 FORMAT(1X,/,1X,'COSTS PER UNIT PLACED',/,1X,
     ^'ENTER DOLLARS PER UNIT PLACED')
      READ(1,*)DPU
      WRITE(1,610)
  610 FORMAT(1X,/,1X,'ENTER DESCRIPTION')
      READ(1,615)JM1,JM2,JM3,JM4,JM5
  615 FORMAT(5A4)
      WRITE(2,620)DPU,JM1,JM2,JM3,JM4,JM5
  620 FORMAT(1X,12X,'$',F7.2,10X,5A4)
      SDPU=SDPU+DPU
      WRITE(1,625)
  625 FORMAT(1X,/,1X,'ANOTHER UNIT COST?(Y/N)')
      READ(1,630)IYON
  630 FORMAT(A1)
```

```
      IF(IYON.NE.IYN)GO TO 635
C
      MAX=IOSA+IODW-1
      IF(MAX.GT.MAXA)MAXA=MAX
      INS=IODW-IOID+1
C
      IQM=1
      DO 150 I5=INS,IODW
      I6=IOSA+I5-1
C         TIME
      T=I5-(IODW-IOID)-0.5
C         PRODUCTIVITY
      PDD=R(1)+R(2)*T+R(3)*T**2.0
C           RATE OF PLACEMENT OF WORK UNITS
      P1=BI/IOID**(QD-1.0)
      P2=T**(PD-1.0)
      P3=(IOID-T)**(QD-PD-1.0)
      QP=OQ*P1*P2*P3
C            NUMBER OF MAN REQUIRED
      QMANO(IQM)=(QP/PDD)/(RHPW+PHPW)
C             LABOR COST
      HUM=QMANO(IQM)*(RHPW*RWR+PHPW*PWR)
C              UNIT COST SUMMATION
      ZUC=SDPU*QP
C              TOTAL COST-RATE OF CASH FLOW
      ACT(I6)=HUM+ZUC+ACT(I6)
C             TOTAL MANPOWER
      QMANP(I6)=QMANP(I6)+QMANO(IQM)
      IQM=IQM+1
  150 CONTINUE
C
C              TOTAL WEEKLY CASH FLOWS
C
      DO 188 KZA=1,IODW
      KZA1=KZA-1+IOSA
      ACT(KZA1)=ACT(KZA1)+OP1(KZA)
  188 CONTINUE
C
C           PRINTOUT OF SHIFT/OPERATION MANPOWER PROFILE
C
      IF(NUMO.EQ.1.AND.NUMS.EQ.1)GO TO 2020
C
      QMXO=0.0
      DO 2000 KW=1,IODW
      IF(QMANO(KW).GT.QMXO)QMXO=QMANO(KW)
 2000 CONTINUE
C
      QMXOA=QMXO*1.2
      JQM1=INT(QMXOA/5.0)
      JQM1CH=JQM1*5
      IF(JQM1CH.LT.QMXO)JQM1=JQM1+1
      JQM2=JQM1*2
      JQM3=JQM1*3
      JQM4=JQM1*4
      JQM5=JQM1*5
C
      WRITE(2,2005)JQM1,JQM2,JQM3,JQM4,JQM5
```

```
 2005 FORMAT(1X,/,1X,/,1X,50X,'SHIFT/OPERATION MANPOWER',/,1X,
     ^25X,I7,13X,I7,13X,I7,13X,I7,13X,I7,/,1X,
     ^28X,'I',19X,'I',19X,'I',17X,'I',19X,'I',/,1X,9X,
     ^'TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT',
     ^'TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT')
C
      DO 2010 JAZZ=1,IODW
      IQMO=INT((QMANO(JAZZ)/JQM5)*100.0)
      JPROD(IQMO)='*'
      WRITE(2,2015)(JPROD(J99),J99=1,100),JAZZ
 2015 FORMAT(1X,8X,'I',100A1,/,1X,'WEEK ',I3,'I')
      JPROD(IQMO)=' '
 2010 CONTINUE
 2020 CONTINUE
C
   42 CONTINUE
   15 CONTINUE
C
C
      WRITE(2,159)
  159 FORMAT(1X,/,1X,/,1X,'*****ACTIVITY CASH FLOW*****',/,1X,
     ^'   WEEK                $/WEEK')
C
      AAMT=0.0
      DO 155 IB=1,MAXA
      WRITE(2,160)IB,ACT(IB)
  160 FORMAT(1X,3X,I3,4X,F15.2)
      AAMT=AAMT+ACT(IB)
  155 CONTINUE
C
      WRITE(2,162)AAMT
  162 FORMAT(1X,/,5X,'TOTAL ACTIVITY COST $',F15.2)
C
C          GRAPHICAL DISPLAY OF ACTIVITY CASH FLOW
C
      IODD=IOSA+IODW-1
      MAXACT=0
      DO 200 I7=1,MAXA
      IF(ACT(I7).GT.MAXACT)MAXACT=ACT(I7)
  200 CONTINUE
      AXG=MAXACT
      I8=1
  220 CONTINUE
      AXG=AXG/10
      IF(AXG.LE.100)GO TO 210
      I8=I8+1
      GO TO 220
  210 CONTINUE
      IMAXG=INT(AXG)
      IMAXG=IMAXG+1
      IMAXG=IMAXG*10**I8
      IQ1=INT(IMAXG/5.0)
      IQ2=IQ1*2
      IQ3=IQ1*3
      IQ4=IQ1*4
      IQ5=IQ1*5
      WRITE(2,230)IQ1,IQ2,IQ3,IQ4,IQ5
```

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I: LICENSED RESTRICTED RIGHTS AS STATED IN License CL-0002          **
  230 FORMAT(1X,/,1X,/,1X,50X,'ACTIVITY CASH FLOW ($/WEEK)',/,1X
     ^25X,I7,13X,I7,13X,I7,13X,I7,13X,I7,/,1X,
     ^28X,'I',19X,'I',19X,'I',19X,'I',19X,'I',/,1X,9X,
     ^'TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT',
     ^'TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT')
      DO 461 JAZ=1,MAXA
      IACT=INT((ACT(JAZ)/IQ5)*100.00)
      JPROD(IACT)='$'
      WRITE(2,462)(JPROD(I10),I10=1,100),JAZ
  462 FORMAT(1X,8X,'I',100A1,/,1X,'WEEK ',I3,'I')
      JPROD(IACT)=' '
  461 CONTINUE
C
      WRITE(2,469)
  469 FORMAT(1X,/,1X,/10X,'*****ACTIVITY MANPOWER*****',/,1X,
     ^'   WEEK              MEN')
      DO 470 K1=1,MAXA
      WRITE(2,471)K1,QMANP(K1)
  471 FORMAT(1X,3X,I3,5X,F10.1)
  470 CONTINUE
C
      QMX=0.0
      DO 480 K5=1,MAXA
      IF(QMANP(K5).GT.QMX)QMX=QMANP(K5)
  480 CONTINUE
C
      QMXA=QMX*1.2
      JQ1=INT(QMXA/5.0)
      JQCH=JQ1*5
      IF(JQCH.LT.QMX)JQ1=JQ1+1
      JQ2=JQ1*2
      JQ3=JQ1*3
      JQ4=JQ1*4
      JQ5=JQ1*5
      WRITE(2,481)JQ1,JQ2,JQ3,JQ4,JQ5
  481 FORMAT(1X,/,1X,/,1X,50X,'ACTIVITY MANPOWER (MEN)',/,1X,
     ^25X,I7,13X,I7,13X,I7,13X,I7,13X,I7,/,1X,
     ^28X,'I',19X,'I',19X,'I',19X,'I',19X,'I',/,1X,9X,
     ^'TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT',
     ^'TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT')
      DO 483 JAZ1=1,MAXA
      IQM=INT((QMANP(JAZ1)/JQ5)*100.0)
      JPROD(IQM)='*'
      WRITE(2,482)(JPROD(J10),J10=1,100),JAZ1
  482 FORMAT(1X,8X,'I',100A1,/,1X,'WEEK ',I3,'I')
      JPROD(IQM)=' '
  483 CONTINUE
      STOP
      END

7D  R04-00     MAINPROG    .MAIN      26/11/82  16:27:08   TABLE SPAC
FFER:   20 LINES/1321 BYTES     STACK SPACE: 221 WORDS
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
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```
      C
      C          GMMA CALCULATION
      C
            SUBROUTINE GMMA(XX,GX,IER)
            IF(XX-57.0)1020,1020,1025
       1025 IER=2
            GX=1.E75
            RETURN
       1020 X=XX
            ERR=1.0E-6
            IER=0
            GX=1.0
            IF(X-2.0)1030,1030,1035
       1040 IF(X-2.0)1045,1045,1035
       1035 X=X-1.0
            GX=GX*X
            GO TO 1040
       1030 IF(X-1.0)1050,1055,1045
       1050 IF(X-ERR)1060,1060,1065
       1060 Y=FLOAT(INT(X))-X
            IF(ABS(Y)-ERR)1070,1070,1075
       1075 IF(1.0-Y-ERR)1070,1070,1080
       1080 IF(X-1.0)1065,1065,1045
       1065 GX=GX/X
            X=X+1.0
            GO TO 1080
       1045 Y=X-1.0
            GY=1.0+Y*(-0.5771017+Y*(0.9858540+Y*(-0.8764218
           ^+Y*(0.8328212+Y*(-0.5684729+Y*(0.2548205
           ^+Y*(-0.05149930)))))))
            GX=GX*GY
       1055 RETURN
       1070 IER=1
            RETURN
            END

7D  R04-00    SUBROUTINE  GMMA      26/11/82  16:27:09  TABLE SPAC
FFER:  20 LINES/1321 BYTES    STACK SPACE: 297 WORDS
SION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
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What Was That Again?

THE INCREASED RIGOR OF SCIentific investigation is resulting in a tougher look at the imprecise or dissembling phrases often found in research papers. Someone who had come across one too many of them compiled this list of research definitions, copied from the *Natural Hazards Observer*, a newsletter published by the University of Colorado.

It has long been known — I haven't bothered to look up the reference.

Of great theoretical and practical importance — Interesting to me.

Though it has not been possible to provide definite answers — The experiment didn't work out, but I need the publicity.

Typical results are shown — The best results are shown.

Presumably over longer times — I did not take the time to find out.

The most reliable results are Smith's — He was a student of mine.

It is believed that — I think.

It is generally believed that — A couple of other folks think so too.

Thanks are due to Joe Glotz for help with the experiments and to Jane Jones for valuable discussions — Glotz did the work and Jones explained to me what it meant.