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DECISION MANAGEMENT - PROJECTS SUBJECT TO UNCERTAINTY

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ABSTRACT

The human mind is normally unable to grasp more than five to nine aspects relating to the same decision circumstances simultaneously. It has been demonstrated that only between four and eight variables significantly affect return on engineering projects (at the 90% level) irrespective of scale. The most powerful means of isolating these significant variables is by computer simulation. This is demonstrated through the application of the interactive CASPAR programme to a simulated mining project. The significant variables are seperated into controllable, influencable and uncontrollable categories for decision and control purposes since the nature of the speculative risk differs. The managerial treatment of each category is discussed.

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Introduction

Success in business is largely measured in terms of the ability to achieve returns higher than those available from Government bonds. In the latter case while the returns are limited they are sure. To achieve higher returns it is necessary to make decisions that will result, overall, in enhanced advantage. One of the difficulties of making decisions is that the only aspect one may change is the future course of events, however marginally. It is the ability to modify future circumstances to suit our purposes (or to model our purposes to the future that transpires) that influences the returns we achieve. The inherent uncertainties of the future inhibit many decision makers. This uncertainty can, however, be systematically approached to assist with directed decision making.

Capital Projects

Capital projects are investments in the future. They have little intrinsic value. The Promoter is investing resources in order to achieve financial return (and/or some other value) greater than obtainable through alternative, available choices. The life cycle of the project is rarely less than ten and frequently in excess of thirty years. Predictions at the approval stage, upon which the investment decision will be based, are usually imprecise.

One major difficulty faced by decision makers is that the future is inevitably uncertain. Consequently while it is recognised to be beneficial to look to the future, the further one looks the less one can see.

Looking to the future and its uncertainties another problem arises. This is the vast number of variables one seems to need to consider in order to be reasonably satisfied with a decision.

It is the relationship between the uncertainty of the future environment and the significance of the elements that make up that uncertainty that this paper seeks to address.

The paper is divided into two sections. The first discusses the theory of uncertainty and its treatment. The second section introduces a simulation model which identifies potential uncertainties and measures the financial impact of those uncertainties on the project. The paper is broadly based on studies undertaken by Paterson [9].

(A) THE THEORY BEHIND THE TREATMENT OF UNCERTAINTY

Human capabilities in Analysis

Before considering the treatment of uncertainty it seems pertinent to consider the human limits for processing information. Able as we are, there are distinct limits to the human capacity for processing even simple fixed unidimensional data. Miller [1] found that for a single decision event human capacity is limited to about seven factors if the decision is to be rationally considered. Contrary to these indicators, however, most people have seen bar attendants who seem capable not only of remembering a multitude of orders but able to recall the orders some while later. This aspect was also mentioned by Miller who suggested that people adjusted to a particular environment are able to amplify their apparent abilities by using stepping stones. An example would be the memory training model introduced by Rider Haggard in his book "Kim", the so-called Kim's Game. As humans we remain limited to about seven discrete factors. If the number of perceived considerations increases beyond this the individual becomes less consistent in his responses unless he can simplify the problem. (Relating a new problem to a similar past problem is one method of simplification which can reduce uncertainties but which may or may not prove appropriate).

This very human limitation is an important restraint to consider as we delve into computer simulations which can assist our decision making.

Clearly as we move from static considerations to dynamic situations and, consequently, to increased uncertainty resulting from prediction of the nature of changes, the human capacity for analysis is even more restricted.

Significant uncertainties

When considering the human limitations for processing information it seems fortunate that research has shown that the number of significant uncertainties that can influence outcome to be about 4 to 8. In particular the Severn Tidal Power Scheme, which will be mentioned later, exhibited eight. The scheme is a £20 000 x 10^6 project, far larger than the largest of South Africa schemes. Barnes [2] in his analysis suggests that consideration of the eight largest uncertainties will usually cover as much as 90% of the total exposure. For most work the uncertainties generally fall into the technical, logistical, fabrication, financial, market and/or political classes - all of which interact with time. Until recently, in South Africa, we have been fortunate in working in a stable political and business environment working with a stable currency. What we produced we have been able to sell in a predictable way. This seems to be no longer the case.

Uncertainty

To clarify terms it is appropriate to note the differences between risk, uncertainty and the perception of uncertainty. Unfortunately, risk is often popularly taken as simply the possibility of adverse results, half of a probability curve. But, generally risk and uncertainty include the inability to predict with precision the outcome of a decision or a series of events.
The results could be better or worse than expected. The difference between the two is taken to be that pure risk outcomes will fall within a defined probability curve generated from extensive occurence histories. On the other hand uncertainty describes situations where the probability curve can't be defined other than subjectively. There is really no clear dividing line. But in either case the outcome is likely to be different to the central value most often used for deterministic calculation. Two aspects are important.

The "average" (mean, mode or median) and the range.

The perception of uncertainty does not depend on actual uncertainty as such. Most people are wary about tackling a task not undertaken before, however complete the instructions or exact the outcome. We are wary of the new, the unknown. Unwillingness to use computers is a simple example. The perception of uncertainty relates to individual inability to predict an outcome with confidence. Individuals differ in their willingness to accept uncertainty, to accept the inevitable surprises that result. Whilst most people are uncertainty averse some are more than others. This is even more pronounced when the chance of a loss occurs. We simply do not take an unbiased stance in decision making. This led to the development of team decision making. However, from a utility point of view the results have not been manifestly different [3]. We have difficulty dealing with unpredictability. We abhor the possibility of singe decision failure even if cumulative decisions must yield advantage. We like to be able to predict with confidence. Most management decision models are based on the premis of predictability, some to a greater extent than others. For instance, the decision tree approach depends on the decision makers ability to predict multiple possible outcomes of distinct decision in a precise way.

Uncertainty is, however, a reality in decision making. So far both human limitations in analysis and the limited number of uncertainties that need be considered have been raised. Normally only between four and seven or eight aspects need be considered to absorb the bulk of significance. It is also all we can cope with.

Treatment of uncertainty

Of these four to eight uncertainties some will be controllable, i.e., within the domain of direct control of the decision maker or his organisation; some (such as inflation and exchange rates) will be uncontrollable; others will be subject to influence through agreement.

Treatment of each group will differ. Where elements are subject to control more precise decisions can be made; the influencable category generally requires compromise (the bargaining environment where agreement is achieved in a win-win situation (1)). Local trade unions, businesses and, sometimes, politicians fall into the latter category. Where no control is possible one either transfers the uncertainty or allows some contingency outlet. In the latter case the decision is generally difficult to reverse.

Decision makers, normally, respond to four considerations : ability to control or influence, ability to pay for the consequences, ability to foresee and the likelihood of occurance.

There is always a cost to uncertainty. That cost is normally reated to the speculative risk of an investment. Given that there is no overriding circumstances or set of circumstances which preclude investment, (however attractive the project may otherwise be) the rational decision maker tries to minimise the perceived cost of uncertainty - as distinct from replace all uncertainties with certainties. Insurance is an example of replacing an uncertainty with a certainty.

Mason [4] cites four basic methods of speculative risk treatment. These are risk avoidance, risk abatement (reduction), risk retention and risk transfer (or some combination of these). The purpose is to minimise cost. Clearly it hardly makes sense, for instance, to transfer a risk where the cost of transfer is greater than the value ascribed to the risk itself. Consequently, contingency allowances often make sense. Movements in this direction are evident in South Africa today as short term insurers escalate premiums.

Identification of uncertainties

So far the assumption has been made that the major uncertainties have been identified. It has also been assumed that the interdependence between uncertainties is known.

The next section sets out to explore a particular computer simulation model which helps decision makers identify the reality of the whole situation.

(B) THE COMPUTER SIMULATION MODEL

The model used in this analysis was developed by University of Manchester Institute of Science and Technology (UMIST) [8]. The simulated case study is based on a similar analysis by UMIST. The computer model itself is available in South Africa.

The CASPAR model

CASPAR, an acronym for Computer Aided Simulation for Project Appraisal and Review, is a project appraisal and management tool designed to model the interaction of time, resources, cost and revenue throughout the life cycle of a project. CASPAR has the capacity to evaluate the consequences of delay, escalation, and changes to the production rate or to the market which occur at any time during the development or operation. It can assist with the identification and analysis of the financial and construction risks associated with engineering, operation and management of the project.

The CASPAR programme was originally developed by Thompson and Whitman [5] at the University of Manchester Institute of Science and Technology. CASPAR is essentially a Monte Carlo simulation overlaid onto a precedence network. Since 1974 it has undergone considerable improvments. In 1985 the programme was restructed to suit IBM PC usage. CASPAR's main use has been for appraisal studies and cost benefit analysis. These include the Severn Tidal Power Scheme, [6]. It has also been used for the compilation of detailed operational cost estimates for high risk overseas construction contracts and, in a modified form, was used to explore the depletion policy for the North Sea oil fields.

The sensitivity analysis from the Severn Tidal Power scheme is shown to illustrate that even for large scale projects the approach is not to achieve more information but to isolate those aspects which are pertinent. The use of the model for appraisal and risk analysis is developed, below, for a simulated mining venture.

The CASPAR sensitivity analysis of the Severn Tidal Project (shown as Figure 7) shows clearly the impact of delay. The X axis shows NPV while the Y shows percentage changes to chosen variables. As can be seen from the figure, variable (1), (2) and (3) relate to the cost of the turbines, the (time taken in) installation of the turbines and delay in construction respectively. The degree of departure from the vertical shows the sensititity to change. Time is more important, in this case, than cost. Many studies at the University of Manchester Institute of Science and Technology have shown time to be an element frequently overlooked. In the Central Electricity Generating Board's (CEGB) case it was no different. For instance, the cost of turbines was regarded as the highest priority by CEGB engineers. But the speed of availability for use was shown to be of greater significance. (For completeness it should be noted that the next step, after compiling the sensitivity "spider diagram" would be to overlay probability assessments to show the perceived liklihood of a particular varience. The combination enables one to assess the speculative exposure. This is illustrated in Figure 8, taken from another study.)

This presentation of sensitivity data gives a visual plot of the percentage change of a variable from expected against the effect on net present value (NPV) - or the internal rate of return (IRR), if preferred.

CASPAR was developed to facilitate the appraisal of any project involving engineering construction and to provide a tool by which the project can be continuously reappraised and the risk controlled. 'What if' questions relating to a change in any time, cost, or production factor at any stage of project development can be addressed. This enables the evaluation of alternative courses of action. The evaluation is quantified in terms of change in return on investment (in either NPV or IRR terms) and on the associated spectrum of risk.

CASPAR is, thus, designed to simulate the realistic interaction of time and money.

Compilation of the model

The model is normally developed in four stages:-

1. The initial (definitive) model is constructed from a precedence network of inter-related activities to which costs and revenues can be attached in several ways. This basic model will give a single figure estimate of the outcome of the project based on deterministic estimates. It represents the envisaged pattern of development and operation of the project within the constraints set by the Promoter. The model will normally comprise only a small number of activities, normally less than twenty. The resulting cash flows are almost entirely dependent on the correct definition of costs and revenues as fixed, quantity proportional, or time related. Costs may be directly associated with a single activity or defined as indirect costs spanning a group of activities and represented by a hammock (2). The engineering and operational phases of the project are modelled separately.

2. The identification and investigation of major uncertainties. The cost implications of risks and uncertainties can be determined by performing sensitivity and probabilistic risk analyses. The relative effect of delays, changes in costs, revenues and resource efficiencies can be demonstrated. Initially a sensitivity analysis is performed by changing the value of individual independent variables which comprise the basic model. This predicts the effect of a single change in the overall viability of the project.

3. At this stage it is advisable to review the constraints imposed on the project and the pattern of development proposed in the light of the sensitivity analysis. It will be essential to consider how the overall level of uncertainty can be reduced. Frequently the definitive model will be revised.

4. A probabilistic risk analysis is performed using the revised definitive model. In the probabilistic risk analysis different values of the variables are combined in a Monte Carlo simulation to yield a likely return range.

The greatest value of speculative risk analysis in the early stages of a project is to establish confidence limits for the financial predictions and to indicate the adequacy of contingencies included in the sanction estimate. Both sensitivity and probabilistic risk analysis have an important function related to project management as the simulations quantify the consequences of any action or inaction.

It is important to recognise that after commitment to a particular course of action the uncertainties that can be managed need be managed. This often seems forgotton. Extensive feasiblity studies give way to a concentration on the present. On the other hand since they cannot be managed, contingencies related to uncontrollable uncertainties need only be monitored.

Brambia mining development - a simulated mining project

The hypothetical Brambia venture is aimed at exploiting a Randite deposit located in the Province of Brambia. It is situated at an altitude of 1500m, 600km from the port of Rio-Natalia. The climate is sub-tropical with heavy rains during the summer months.

The Randite deposit with payable "rax" levels was discovered as a result of geological studies done in terms of a licence granted by the Brambia Government. The terms of this licence form the basis of the partnership agreement between the corporation and the Government of Brambia and may be summarised as follows:

The Government of Brambia will make available K32000 per month during the construction phase. However, the Government will receive a royalty of K500 per ton of Randite sold regardless of grade.

The Randite deposit occurs in two layers and the grade of Randite is defined by the percentage of commercially extractable rax per ton. The upper layer contains lower percentages of extractable rax. This is reflected in the costs. Market prices for Randite over the last five years have, when adjusted for inflation, varied with grade. This study is based on an average price of K2000 per ton for 3 per cent rax.

It is planned to ship 2000 tons of ore each month from the upper layer to the treatment plant in the first two years and 2800 tons per month thereafter from the lower layer. Mine life is assumed to be 13 years.

Initial plant design and settings will be such as to produce a recovery of 800 tons of Randite each month from the ore delivered to the plant in the first two years.

In CASPAR, rather than stipulating a period cost to an activity or hammock, it is possible to give a quantity of resource used and the cost per unit of resource.

The quantity of resource used by an activity can increase or decrease over time, and a limit can be specified. It is also possible to allow the unit cost of resource used by both activities and hammocks to increase or decrease over time.

The activity duration and the resource growth/decline limits are inter-related. The duration of an activity will be the number of time periods required for the resource usage to grow or decline from the initial level to the limit. This is illustrated by the second stage of the venture. The second stage envisages the construction of an extension to the plant.

The extension to the plant will improve the recovery rate to 1120 tons of Randite each month. It is estimated that this rate will grow by 6 per cent each year, until the maximum possible recovery rate of 1800 tons per month is achieved.

Calculation of the precedence network

The time relationship between activities can be expressed in a precedence diagram (Fig. 1).

The network can be calculated by either early or late start dates. The Brambia venture is terminated by a project finish date, thus allowing only 13 years for operation. The network will always stop calculations at this point.

Costs and revenues

Costs and revenues may be associated with any activity or resource hammock and can be defined in several ways to give any desired pattern of cash flow. Cash flow in or out may be divided into fixed, time related and quantity proportional costs or revenues. Lump sum moneys may be spread or applied at any discrete time.

Flexibility in the allocation of costs and revenues is allowed by permitting a series of dates at which the resource data can change. Advanced or delayed payment on any cost centre can also be specified.

Discounting, escalation, and deflation

The values calculated can be either in money of the day terms or real terms. Different escalation rates can be allocated to each cost centre and, to reflect likely differences in the rates, can also be altered in time. Discounting is applied to either set of results separately. This is the technique used to adjust the cash flows to present day values.

The discount factor is generally a constant value, but the program does permit change to this value over time. The Brambia venture uses a rate of 10 per cent to discount the cash flows to the start of the project.

The escalation/inflation data will give the final result in money of the day terms. Perry and Thompson [7], however, consider that investment decisions should be based primarily on the real (non-escalated) cash flows. To obtain real values the final values need deflating back to present values.

Costs and revenues associated with a project may be spread over several years. Delays may well have an important effect on its viability. So it is important to use criteria of profitability which take timing into account. CASPAR uses discounted cash flow techniques to assess the profitability of a project.

Application of the CASPAR model to the Brambia venture

(1) Stage 1 calculates the most probable outcome of the Brambia venture. This yields:

- a payback period of nearly seven and a half years (Fig. 2)
- a net present value (NPV) of approximately K38.3 million at 10% discount rate
- an internal rate of return (IRR) of 24.29%

This return will only be achieved if all predictions over the entire life of the project are precisely fulfilled. As this is unlikely, the implications of change in any of the factors likely to produce a significant effect on return must be analysed by performing risk analysis.

(2) Stage 2,the risk analysis, considers the likely variations affecting the Brambia venture. These include:

Table 1

Variable Descriptions and Ranges for Risk Analyses

Variable	Change from basic value Lower (%)	Upper (%)
1 Recovery of Rax	-30	20
2 Selling Price	-30	60
3 Design Period	- 5	50
4 Construction Period	- 5	50
5 Growth Rate	-50	50
6 Project Life	-20	20
7 Ore Delivered to plant	-20	20

CASPAR allows the user to define a number of variables (which may themselves be risks e.g., delay; or factors affecting the project e.g., efficiency of production) and permits the alteration of these variables over a percentage range change. These variables, are themselves defined in terms of the various elements of the original deterministic data. Any percentage change in a particular variable affects all activities dependendent on the variable to the same extent.

(3) For Stage 3, the sensitivity analysis, CASPAR takes each chosen variable in turn and alters the variable over the defined range in a given number of steps. For each change new financial parameters are calculated. A range of outcomes is produced. Figure 3 shows the spider diagram. The most sensitive factor in this project is the selling price of the rax. A 10 per cent increase in the selling price, from K1500 to K1650 (allowing for Government royalty), gives rise to an increase in NPV of nearly K13 million or 30 per cent. Timely completion of the construction phase is also important. The value of this spider diagram is that it focuses attention on the more sensitive factors and thereby encourages management to consider ways of reducing the uncertainties that can be reduced.

(4) Stage 4 is the probabilistic risk analysis. It is likely that some combination of changes to the variables considered individually during the sensitivity analysis will occur. To assess the implications of different statistical distributions and the combination of the variables CASPAR performs a full probabilistic risk analysis.

The technique behind the probabilistic risk analysis is that of Monte Carlo sampling. The accuracy of the final distribution will depend on the number of variables considered and the number of iterations performed.

A triangular probability distribution has been assumed for each variable over the range of variation shown in Table 1. The three points of the triangular ditribution represent the realistic optimistic, the expected (as used in the first phase of the simulation) and the pessimistic forecasts. The range specified for each variable indicates the degree of uncertainty about the original predictions felt by the Promoter. In this case he feels that overrun on both design and construction is much more likely than early completion, whereas the project life is seen as being uncertain but with equal likelihood of being shortened or lengthened.

The results of 1000 iterations are shown, using IRR as the criterion, in Figures 4 and 5. Figure 4 shows an almost equal likelihood of achieving any value for IRR between 15 and 28 per cent. The mean value of 23.71 per cent should replace the original prediction of 24.29 per cent as the most likely value. Figure 5 presents the information in the form of a cumulative frequency curve, the likelihood of achieving a particular value of IRR. For example, there is a 5 per cent likelihood that it will be less than 19 per cent, and a 60 per cent likelihood that it will not exceed 25 per cent.

CASPAR provides further output which combines elements of both risk techniques. The probability distribution defined for the probabilistic risk analysis is applied to each variable in turn. This is plotted against the range of outcomes as given by the sensitivity analysis. The resulting cumulative probability diagram gives an indication of the probability of achieving various values of the economic parameters, for each variable (Fig.6).

Correlation

CASPAR includes a subroutine which allows correlation. One variable may be directly affected by another; delay in design may affect delay in construction for example. To simulate real situations more closely, there is a need to link the randomness of certain variables: to allow a degree of correlation. At its extremes, correlation is easy to visualise and define. If one variable is totally independent of another it has no correlation. If it is fully dependent it has complete correlation. The concept of partial correlation is, however, less easy to define. As a result, partial correlation factors are normally omitted from most models. Activities are regarded either as totally independent or as completely dependent.

Conclusion

The need for decision making is always with us. Computer simulation has distinct advantages in assisting our ability to understand. This paper set out to illustrate the limited capacity of the human mind in the accomodation of the recognised needs of decision making and the extent to which the power of computer simulation can be used to asist decisions. The CASPAR model was discussed. Fortunately the limits of human capacity are suited to the bulk of decision needs even for very large investments. But there is a need to isolate that information that is pertinent, is sufficiently accurate and is timely relative to the needs of decision making. This also isolates where attention should be paid in the later management. The disadvantages of information overload far outweighs its advantages. However, we need to accept a degree of uncertainty in information just as we need to accept uncertainty in predicting the future we wish to modify to our advantage. Detailed deterministic models may give single value answers but the answers are only as valuable as the input is accurate. A probable range makes more sense in strategic decision making.

NOTES

(1) Compromise and the "win-win" solution. Rationally, agreement will only be achieved if it appears to yield a more attractive altenative to no agreement. The compromise results in net advantage, the win situation. There is no sense of optimisation in the use of the word "win", merely the achievement of the best possible solution under all the prevailing circumstances.

(2) A hammock is a resource levelling device which represents the use of a common resource between a number of activities. The common resource, such as a design office or project management team, is allocated to an indirect cost centre.

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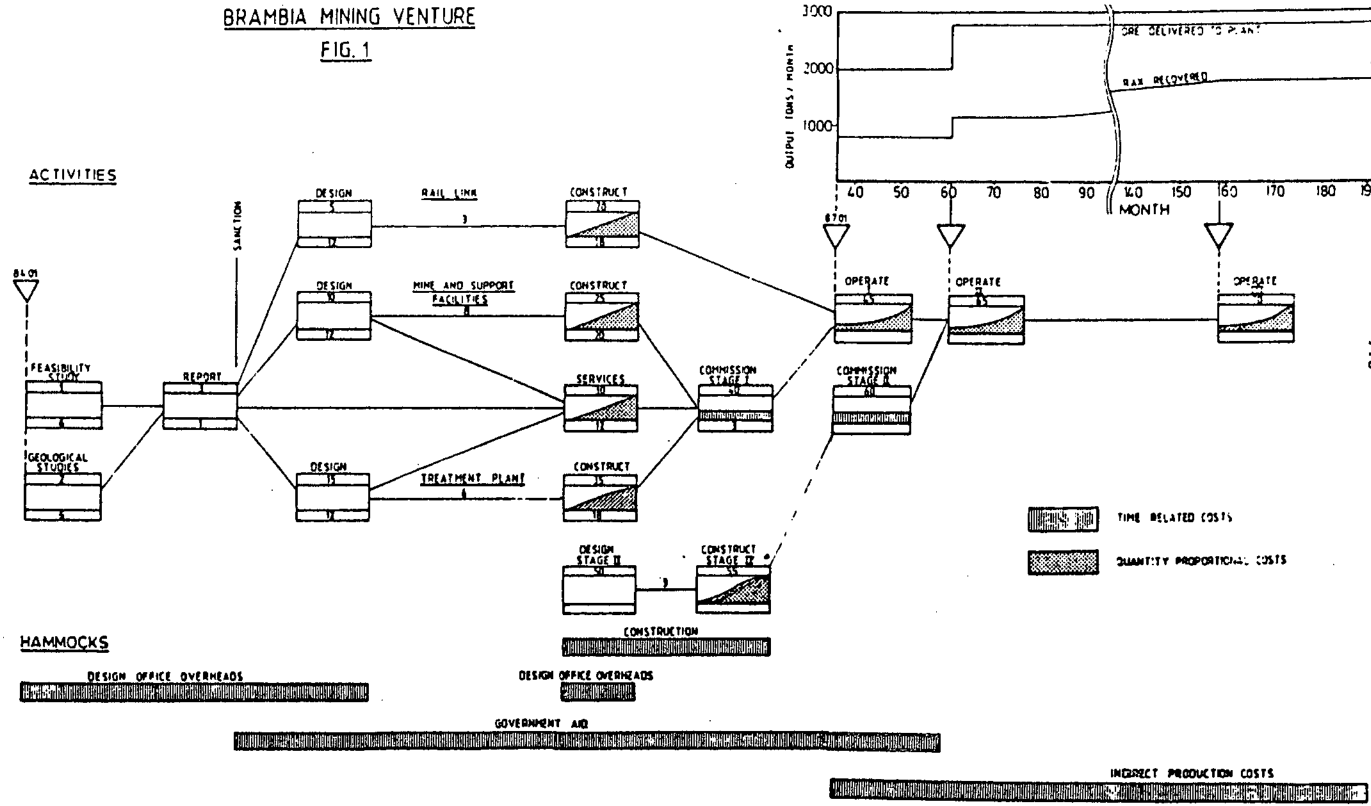
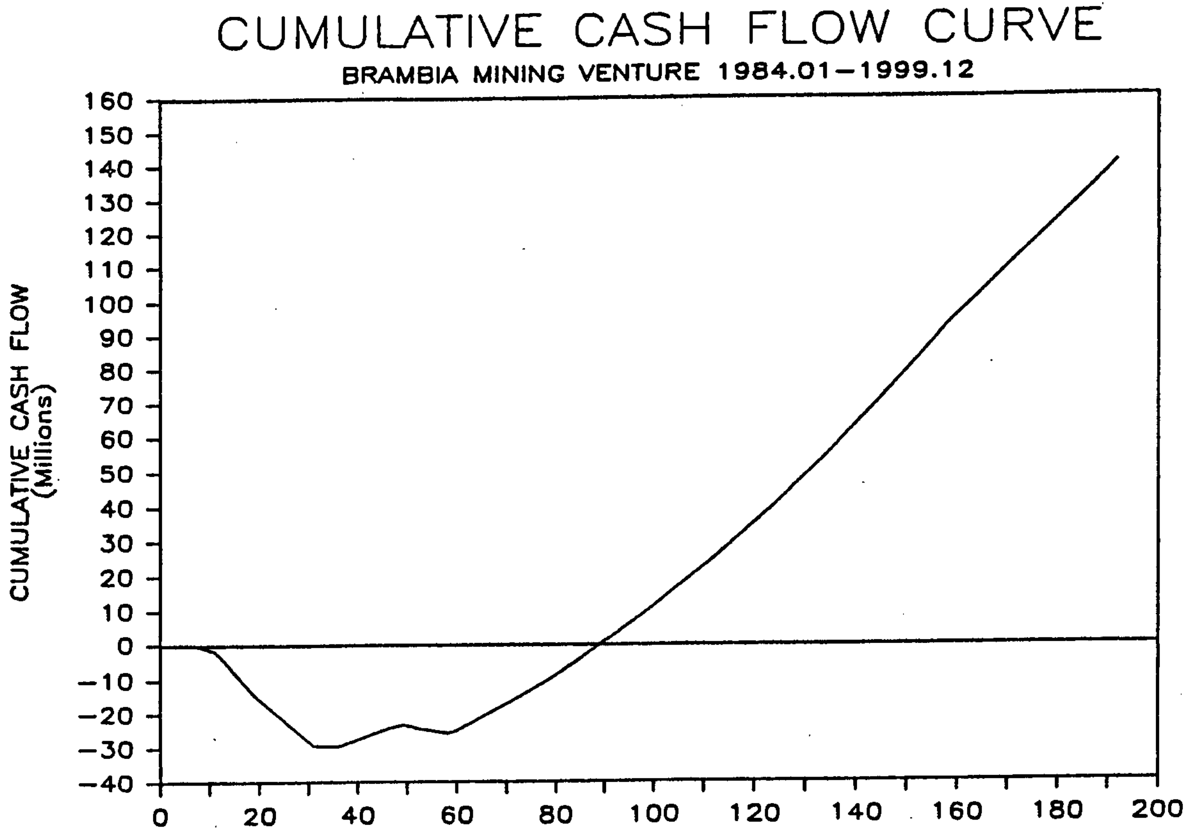
Appendices - 5 pages of diagrams

FLOW CHART FOR COST MODEL OF PROJECT

BRAMBIA MINING VENTURE

FIG. 1





CUMULATIVE CASH FLOW CURVE
BRAMBIA MINING VENTURE 1984.01–1999.12
CUMULATIVE CASH FLOW (Millions)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
−10
−20
−30
−40
0
20
40
60
80
100
120
140
160
180
200
PERIOD NUMBER (MONTHS)

FIGURE 2

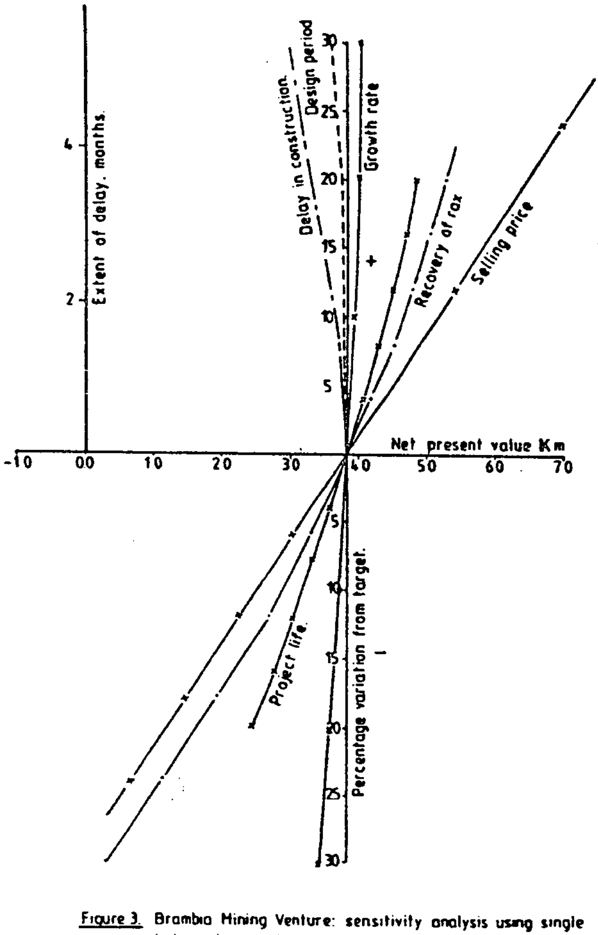


Figure 3. Brambia Mining Venture: sensitivity analysis using single independent variables.

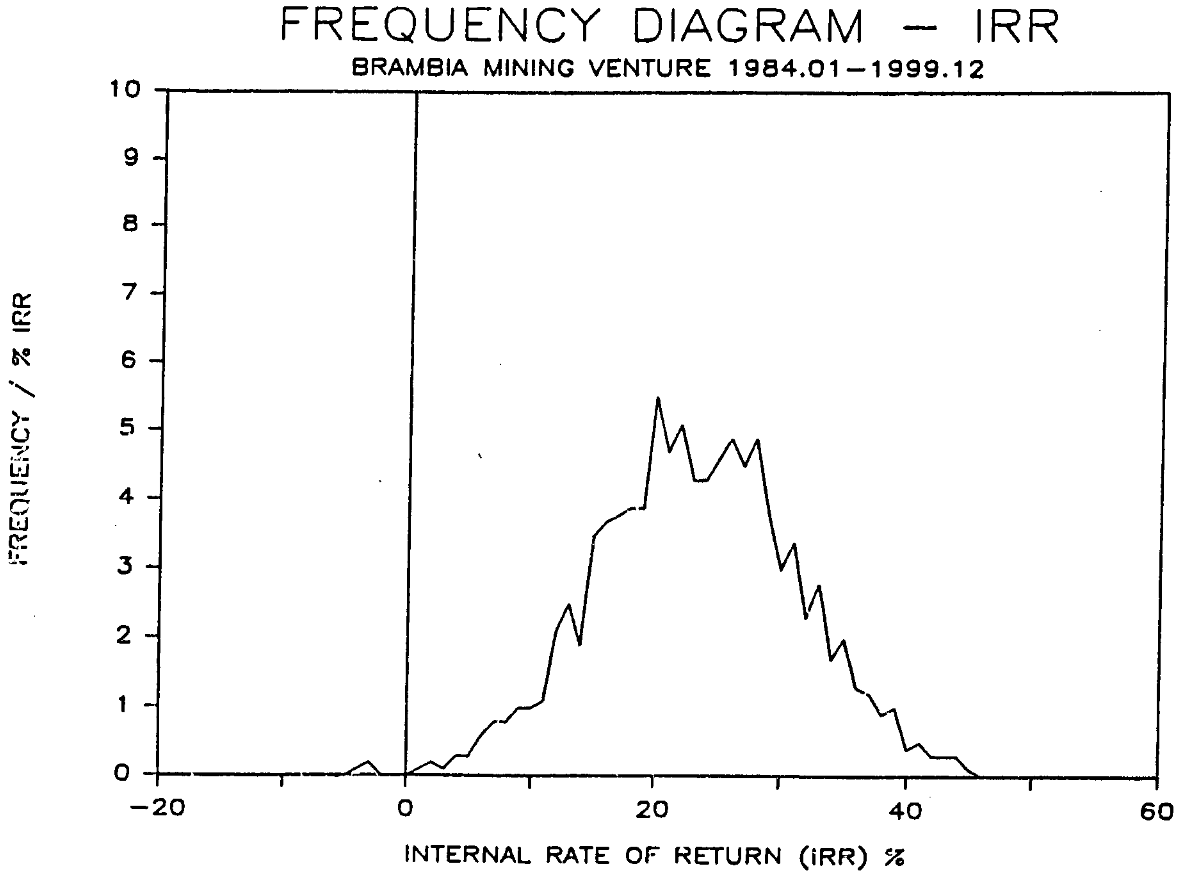

FREQUENCY DIAGRAM — IRR
BRAMBIA MINING VENTURE 1984.01—1999.12
FREQUENCY / % IRR
INTERNAL RATE OF RETURN (iRR) %
0
1
2
3
4
5
6
7
8
9
10
−20
0
20
40
60

FIGURE 4

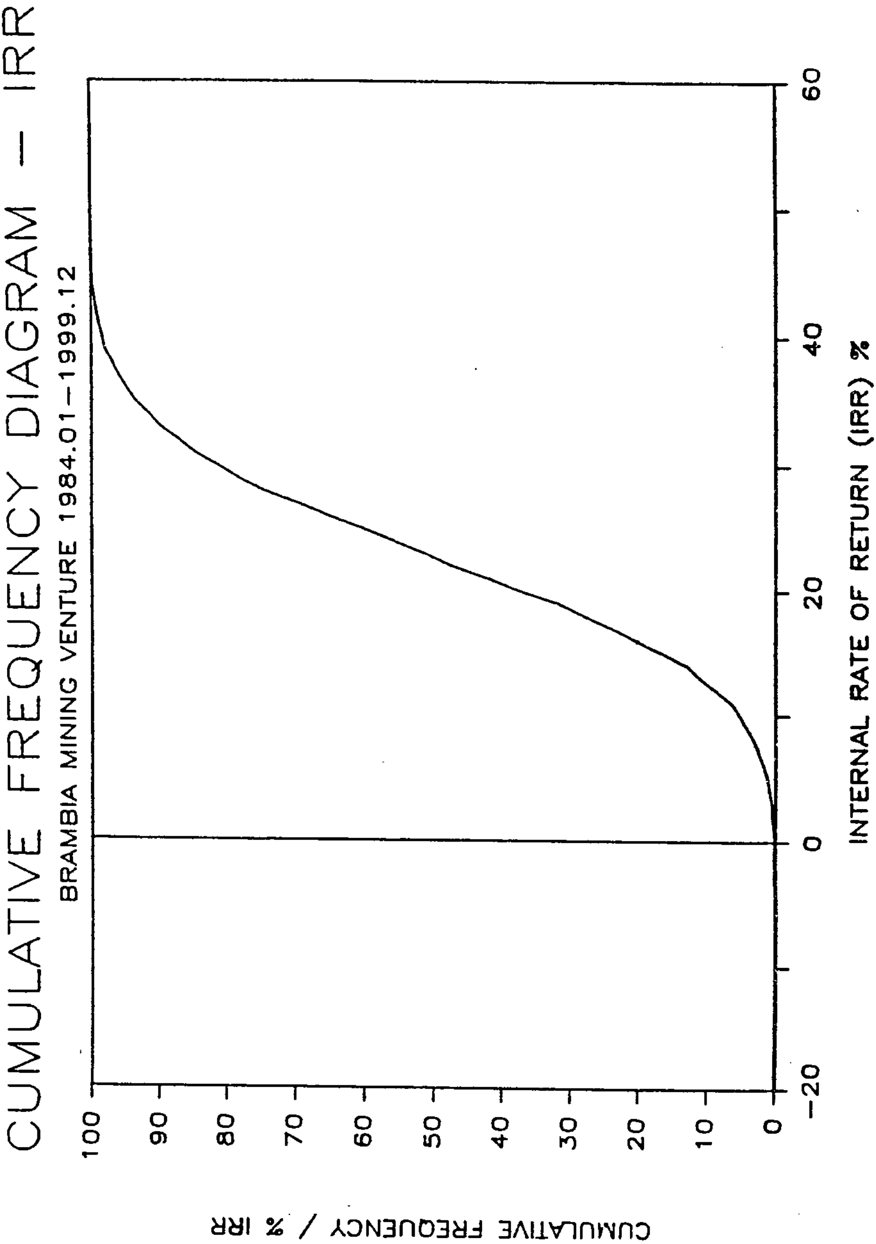

CUMULATIVE FREQUENCY DIAGRAM — IRR
BRAMBIA MINING VENTURE 1984.01—1999.12
INTERNAL RATE OF RETURN (IRR) %
CUMULATIVE FREQUENCY / % IRR
-20
0
20
40
60
0
10
20
30
40
50
60
70
80
90
100

FIGURE 5

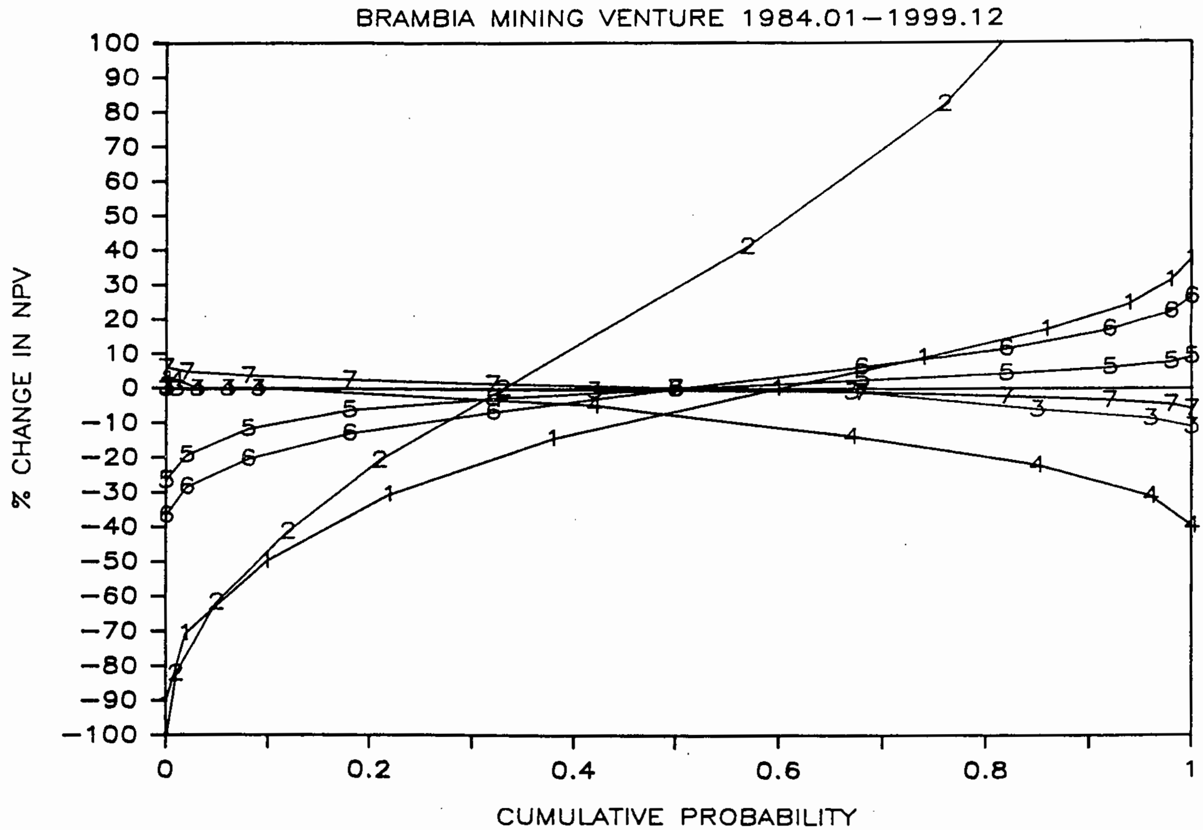
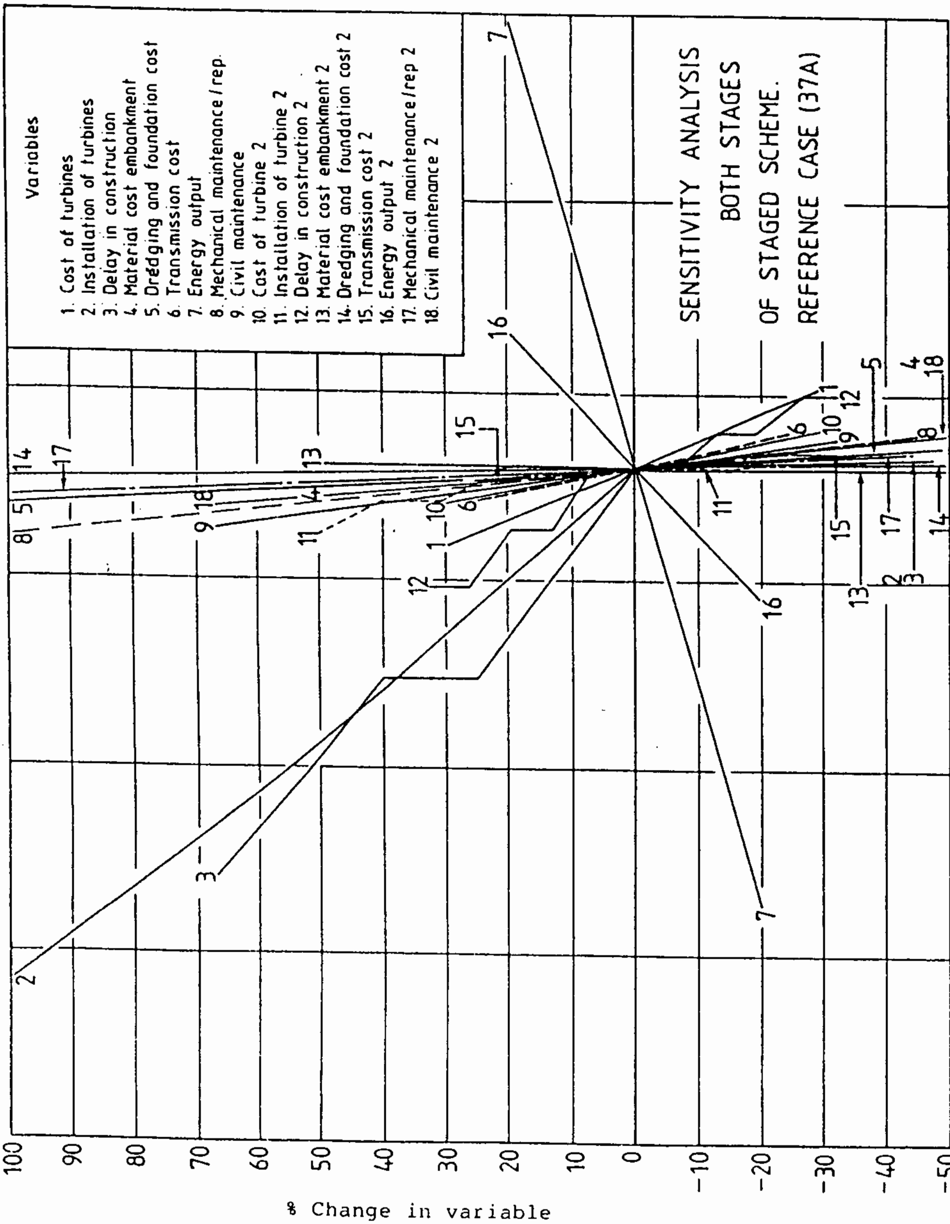
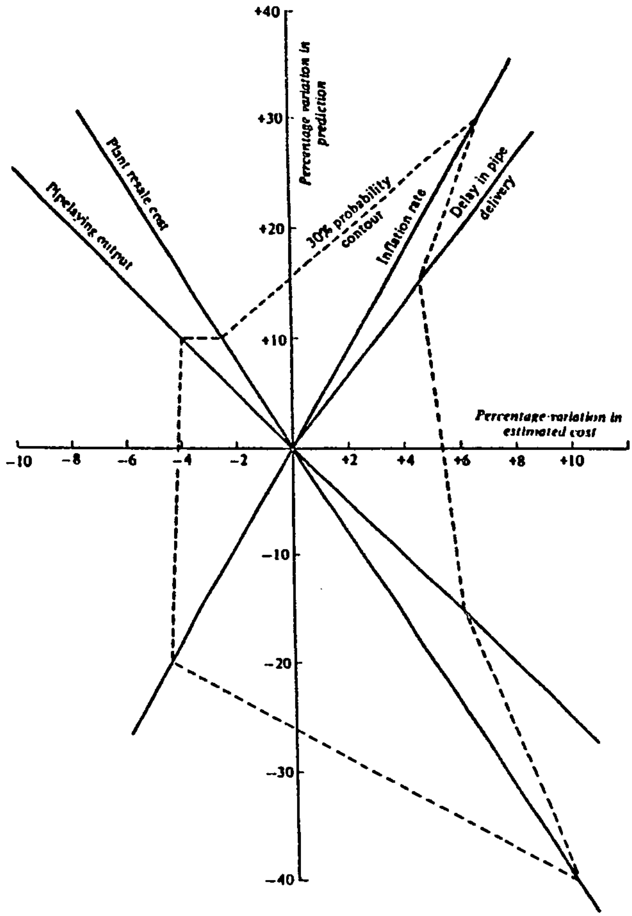


FIGURE 6

(Numbers refer to variable numbers; Table 1)



SENSITIVITY ANALYSIS
FIGURE 7



PROBABILITY CONTOURS

FIGURE 8