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THE EVALUATION AND CONTROL OF RESEARCH AND DEVELOPMENT PROJECTS.

A thesis presented for the degree of Ph. D

in the University of Stirling.

by

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INTRODUCTION.

In recent years the funds spent on research and development (R & D) have grown considerably. An indication of the extent of the growth in the U.K. was given by Hart (1) who noted that in 1900 approximately 0.05% of the gross national product was spent on research. This percentage increased to 0.25% in 1938, 1.6% in 1954 and 2.7% in 1962. Villiers (2) quotes a similar growth in the U.S., where research expenditure grew from $<1\%$ of gross national product in 1947, to about 3% in 1962. (In the U.K. it appears, from some statistics produced by the Ministry of Technology (3), that research expenditure has remained at $\sim 2.7\%$ of GNP over the period 1962-1967).

The allocation of these resources poses a number of challenging questions in governmental, industrial and academic spheres. At a national level the kind of questions that might be asked are (a) what proportion of the gross national product should be devoted to government sponsored research, or (b) how should funds be divided between the claims of the aerospace, computer, or machine tool industries, or (c) how should funds be divided between the competing claims of the nuclear physicists and marine biologists. The large industrial concern is faced with similar problems though the resources involved are smaller. ICI for example spent about £30M on R & D in 1968, and during the later 1960's, the growth rate was about 8% per year. The Company must decide on the total amount to be spent on R & D and how it is to be allocated between different Divisions of the Company and different research categories. At lower levels of management two of the questions arising are (a) which projects shall be selected, and (b) how should the flow of resources to projects be controlled.

It is now generally accepted that there is a need for techniques for assisting in the management of R & D. Jones (4) summed up the situation well when he wrote "It is not surprising that there is an increasing amount of discussion on the management of R & D for profit. Business becomes increasingly competitive and R & D activities, just as those of production and marketing must be examined to see how they can best play their part."

Already a large number of relevant papers have been published, but as yet no significant breakthrough has been achieved. An important feature of the literature has been the concentration on theoretical models as a means of assisting research managers: reports of new methodology considerably out-number reports of practical testing of the methods in research laboratories. Throughout the author's research the opposite bias, that is to say towards a practical rather than a theoretical approach has been maintained. This was facilitated by the author completing most of his research in the R & D Department of the Mond Division of ICI (of which he is a member).

The research presented in this thesis began with the very general objective of examining and developing methods for the allocation of resources (capital and manpower) to R & D and so Chapter 1 discusses some relevant methods that have been proposed in the literature. It was later decided to concentrate on the development of an improved system of project evaluation and control. Chapter 2 analyses an established system in this field, and looks at past projects to demonstrate some of the problems such a system should accept. Later chapters present the system that was developed during the research and record experience of testing the various procedures on a number of Mond Division R & D projects. As these are either still in progress or are only recently completed it has been necessary, for reasons of security, to limit descriptive detail and to normalize numerical data. Such normalization has been made in a manner that preserves the essential financial characteristics of the project.

It is well perhaps, in the Introduction, to distinguish between the terms research and development. Following Baines, Bradbury and Suckling ((5), page (2)) process definition will be the term used to cover the steps required to take exploratory production activities from laboratory scale to full-scale. Development will refer to the problems of opening up a business area with a new product and will include economic assessment and marketing activities. For the most part these activities are closely linked to research activities and are usually performed by members of the same project team. The convention followed in the thesis will be to use the term 'research' to refer to all the activities of the project team and to assume that these also include some development activities as defined above. Only when discussing the work of others who have used the term R & D, or when there is a reason to emphasise the commercial exploitation content of a project will the word development be used.

The work to be described is submitted to meet the requirements of the Ph.D degree in Technological Economics at the University of Stirling. (One academic year of the author's research programme was spent in the Department of Industrial Science of the above University). For permission to publish the results of his research and for generous support throughout the author is indebted to the Directors of Mond Division and of ICI Limited. He also wishes to record his thanks to his colleagues at Stirling University and Mond Division for numerous helpful comments and discussions. Most of all he wishes to thank his academic and industrial supervisors Professors F.R. Bradbury and C.W. Suckling for their patience, guidance and encouragement during a most stimulating piece of research.

Chapter 1.

RESOURCE ALLOCATION IN RESEARCH: A REVIEW OF THE LITERATURE.

The problem of allocating resources to research may be subdivided by considering the allocations (1) to the research function as a whole (2) to different categories of research, and (3) to individual projects. The author's research was principally concerned with the third of these classes. Nevertheless, for reasons of completeness, and of extensive interaction and overlap, it is felt that it would be useful to begin this review with a discussion of some of the methods for dealing with the problems of allocation of funds in the first two classes. The majority of the chapter, however, is devoted to the problems associated with allocating resources to individual research projects. These are discussed under the main headings of checklists, scoring models, financial criteria, analysis of uncertainty, decision theory, project portfolios and project control.

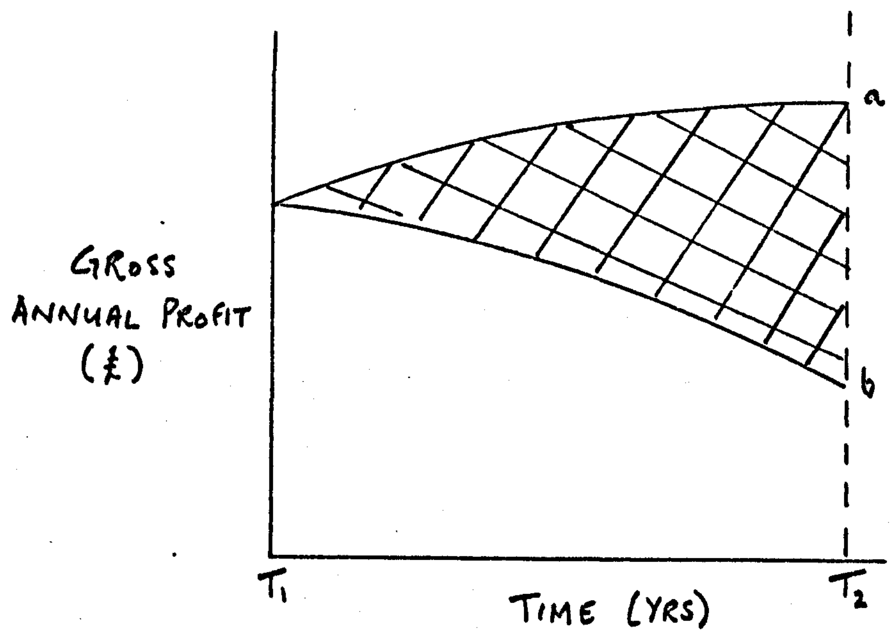
1.1 Methods of allocating funds to the research function as a whole and to different research categories.

Carter and Williams (6) made a survey of research activity in 144 firms and divided decisions on the total amount to be spent into three classes: topsy, elliptical and fully considered.

(1) Topsy Decisions.

The allocation of funds on the basis of 'topsy decisions', as might be expected, just grew. Several firms, with procedures falling into this class, indicated that the present allocation seemed about right, since either the profit margin had been maintained or the R & D Director had not pressed for more funds. An attempt to add formality to this rather arbitrary procedure has been made by Hart (7), who proposed a method of determining the maximum amount that may be spent on research. Two forecasts of 'gross profit' (net profit and research expenditure) are required corresponding to (a) continuing research at an acceptable level (e.g. the present level) and (b) stopping research.

Figure 1.1



These forecasts are shown in Figure 1.1. The maximum amount which may be spent on research over the period T_1T_2, was suggested to be the discounted value of the shaded area between the curves. Clearly the forecasts (a) and (b) are difficult to make, and Duckworth (8), commenting on the method, noted that the amounts predicted are usually well above the existing norms for particular industries. However, Duckworth also produced evidence to show a decline in the productivity of research with time, and suggested that eventually the figures given by Hart's method may not be so unrealistic.

(2) Elliptical Decisions.

'Elliptical decisions' provided a more precise, though not necessarily more rational, basis for allocation. In these cases a certain percentage of a key parameter was used to indicate the level of research expenditure. Examples could be x% of turnover, or y% of net profit. It is sometimes recommended that the amount spent on research should match that of similarly placed competitors, or indeed the market leader, in the firm's field of interest. Thus in the chemical industry, the research budgets of du Pont or ICI might serve as the basis for deciding the R & D budgets of smaller firms in the industry. There is evidence to suggest that budgeting in this manner is common, and that within an industry fairly uniform proportions of available resources are allocated to research. Duckworth (8) quoted the following table taken from 'Industrial R & D Expenditure 1958' published by H.M.S.O. 1960.

Industry	% of Net Output Allocated to R & D
Aircraft	35.7
Electronics	11.9
Instruments	11.0
Electrical	9.8
Chemical	6.0
Non-ferrous	2.1
Ceramics, glass, cement	1.1
Steel	0.9
Food, drink, tobacco	0.6
Wood, paper, printing	0.25

The table refers to the average firm in an industry and shows how the percentage of net output spent on research decreases as the rate of technological change within the industry decreases.

(3) Fully Considered Decisions.

'Fully considered decisions' relate the amount to be allocated to R & D to the long term objectives of the firm. This is the basis of the approach suggested in a paper by Quinn (9).

The steps are:

(i) Define the long-term objectives of the organisation.

(ii) Prepare technological, sociological and economic forecasts.

(iii) Determine the 'gap' between the desired objectives, and the achievements expected of the existing business.

(iv) Define the constraints on operations: the public image of the firm, the labour policy, legislation with respect to hazards and effluents etc.

(v) Consider the alternative means of filling the gap. Research may contribute in a number of ways, examples are defensive research to ensure existing products remain competitive, the development of new uses for existing products, and the discovery of new products.

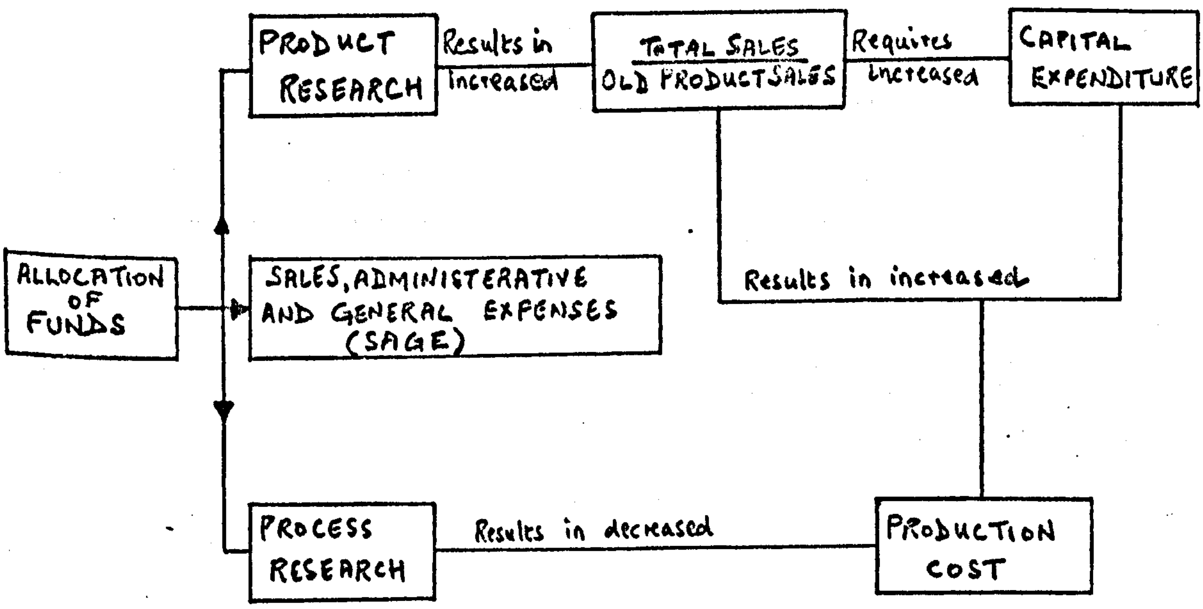
(vi) Fill the 'gap' in the manner that utilises resources most effectively.

A similar approach is developed at length in the books by Argenti (10) and Ansoff (11), though neither pay much attention to research as a means of filling the gap. (A summary of Ansoff's book, which was the basis of some of the thinking in Chapter 5, is provided in Appendix 5.)

Clearly if the 'fully considered approach' were as feasible in practice, as it is suggested in theory, the problems of resource allocation at all levels of the firm would be resolved. However, this is an area in which theory has advanced more rapidly than practice, and in which reports of operational systems are few and far between. Methods tend to fall into two classes: (a) those which are very simple, and (b) those which are highly sophisticated and complex.

The paper by Dean and Sengupta (12), concerned with research in the chemical industry, provides an example of both extremes. Methods were proposed for allocating funds to (a) the research function as a whole, (b) different categories of research, and (c) individual projects. The treatment of (a) and (c) was comparatively simple. Figure 1.2 is the conceptual model used in the exercise.

Figure 1.2



Dean and Sengupta assumed that the total of the funds to be allocated between SAGE (see Figure 1.2) and process and product research was known. The allocation to SAGE (and thus to research as a whole) was then determined by comparison with other members of the US chemical industry. A survey of 16 companies revealed that for each firm the ratio:

Cumulative R & D expenditure/Cumulative SAGE

was related to the firm's average fraction of chemical industry sales. (Cumulation was over the period from a 'base year' to the time of the analysis). The Table below presents the results of the survey.

Average Fraction of Chemical Industry Sales (AF)	$\frac{\text{Cumulative R \& D Expenditure}}{\text{Cumulative SAGE}}$
0.002-0.005	.2
0.005-0.02	.22
0.02-0.04	.27
Greater than 0.04	.36

As the total expenditure on R & D and SAGE was assumed known, then AF determines the allocation of funds between these categories. When the proportion of funds allocated to process and product research had been determined (see below), another simple procedure was suggested for allocating funds to individual projects. Projects were ordered in terms of the expected value (in the statistical sense) of NPV (see Appendix 1) and selection continued until the appropriate funds became exhausted.

On the other hand the method of allocating funds between process and product research was rather complex and difficult to follow. Nevertheless it does represent one of the few methods, which have been reported in the literature, for allocating funds between different categories of research.

The problem was formulated as one of dividing funds between process and product research so as to maximise the criterion:

$$\frac{\text{Sales revenue} - \text{Production costs} - \text{SAGE} - \text{R \& D costs}}{\text{Gross value of plant}}$$

for the next year of operation.

The first step was to express each of the variables in the criterion in terms of cumulative process and cumulative product research. The conceptual model was used as a guide. For example, starting from the base year, cumulative product research and the ratio total sales/old sales (see below) were plotted against time. A relationship between cumulative product research and total sales/old sales was then established. Thus for a given level of old sales, sales revenue (one of the variables in the criterion) was expressed in terms of cumulative product research. (Products introduced before the base year were termed Old, those introduced after were termed New.)

A computer programme was then used to maximise the above criterion and so to divide the research budget between process and product research. The interested reader is referred to Dean and Sengupta's paper for a description of the programme.

It is relevant, before leaving this section, to discuss the work of Mansfield, which is described in his book 'Industrial Research and Technological Innovation' (13). Mansfield adopted an econometric approach, and a particular strength of his study is the attention that was given to testing the proposed models under real-life conditions.

Two of the questions that were considered are:

(1) How much will be spent on research ? (As distinct from the problem of how much should be spent on research).

(2) What is the marginal return on extra research expenditure?

The first of these questions is discussed in Chapter 2 of the above book. The research budget r_i (t) in year t, for the i^{th} firm in the industry (e.g. chemicals, steel, paper), was assumed to be given by:

$$r_i(t) = R_i(t - 1) + \theta_i(t)\left[\tilde{R}_i(t) - R_i(t - 1)\right]$$

where $\tilde{R}_i(t)$ is the desired research expenditure for firm i in year t.

$R_i(t - 1)$ is the actual expenditure for firm i in year (t - 1).

$\theta_i(t)$ is the fraction of the way in which the i^{th} firm moves towards the desired expenditure.

Appropriate values of $\tilde{R}_i$ (t) and $\theta_i(t)$ were determined by postulating further relationships and using regression analysis to fit these to the observed data. (The data were collected from a number of industrial laboratories.) The model was tested by forecasting next year's research expenditure for a group of ten chemical and nine petroleum companies. It was found that on the average, the model made consistently better estimates of research expenditure than three other 'naive' models, which might also have been used:

(1) That research expenditure remains constant from year to year.

(2) That research expenditure will increase next year by the same amount as between this year and last year.

(3) That research expenditure will increase next year by the same proportion as between this year and last year.

The problem of the marginal return of additional research expenditure is considered in Chapter 4 of Mansfield's book (op.cit.) An equation was proposed linking the output of the firm to the labour input, the stock of capital, and the research expenditure. The equation was based on the well-known Cobb-Douglas (14) relation:

$$Q(t) = bL(t)^{a}\, C(t)^{1 - a}$$

where $Q(t)$ is the output of the firm at time t.

$L(t)$ is the labour input at time t.

$C(t)$ is the stock of capital at time t.

b and a are constants.

Further terms, to include the effect of research, were introduced and the marginal return on additional research expenditure e, was then obtained by examination of the derivative of $Q(t)$ with respect to e.

Once again some promising results emerged after practical testing. However Mansfield stressed that any conclusions drawn from this model must be treated with caution, as the model is in the experimental stage of development.

1.2 Checklists and Scoring Models.

The checklist is concerned with exposing the attributes of the project: the strengths, the weaknesses, the areas of opportunity, the areas of threat. For example two of the points of view from which the viability of a project could be examined are (a) the existence of adequate supplies of raw materials, (b) the ability of R & D Department to solve problems of effluent disposal. By exhibiting the attributes in a simple manner, and by ensuring that as far as possible all the relevant points are considered, the checklist helps the project management form a more objective opinion of the project's potential to the firm and allocate resources to different aspects of the project. At the same time, managers must also recognise that checklists are based on past experience and thus must maintain an alertness towards the occurrence of novel situations.

Most checklists take a similar form; a set of factors are arranged on one side of a pro forma with space adjacent for 'rating' or 'scoring' each of the factors. Authors often draw attention to the lack of generality of checklists and advocate that lists be compiled to meet the specific requirements of the firm concerned. Two points that should be considered are:

(1) The Structure of the List of Factors.

It is usual for the list of factors to be presented in a hierarchial form, with perhaps, four or five main factors each with a similar number of subfactors. The main headings define the breath of questioning to be adopted, or to use a term coined by Boulding (15) the 'width of the agenda'. The subfactors define the resolution of the checklist, the greater the number of subfactors, the greater the resolution. It is usual to descend the hierarchy as the project develops, and for the width of the agenda and the resolution of the checklist to increase. Initially it might be sufficient to consider a few factors concerned with process and market. At later times these factors will be considered in more detail. Furthermore other factors related perhaps to the financial and strategic aspects of the project might also be included in the checklist. There is a compromise to be struck of course, between the advantages of a more detailed list and the difficulty of forming an opinion, which tends to increase with the number of factors considered, for example (a 'can't see the wood for the trees' situation may develop).

(2) The procedure for rating factors.

There are usually two parts to the procedure for rating factors, the first is the range of the scale of assessment. Typical examples could be integers in the ranges 1 to 5 or -5 to 5. In each case the lower value refers to a below average achievement and the upper value to an above average achievement. Clearly there can be no hard and fast rules; the aim must be to allow just sufficient freedom to discriminate between levels of performance. The scales adopted by most of the lists appearing in the literature allow less then ten different classifications. A related point is the provision of a 'key' to ensure that factors are rated (by different persons) relative to a well defined frame of reference.

A wide variety of approaches to these points is evident. For example, the list devised by Harris (16) had a wide agenda, (four main headings were employed: Financial aspects, R & D aspects, Production and Engineering aspects, Marketing and Product aspects; with respectively 4,4,4,14, subfactors). Each subfactor was rated on the scale -2, -1, 1, 2 and a 'tight' key was suggested. For example the key corresponding to the factor 'research investment payoff time' (T), was given by:

(i) If, $T > 3$ years, assess factor : -2.

(ii) If, $2 < T \leq 3$, assess factor : -1.

(iii) If, $1 < T \leq 2$, assess factor : 1.

(iv) If, $T \leq 1$, assess factor : 2.

In contrast the checklist described by Pessemier (17) had a narrow agenda and high resolution. Subfactors were presented under two main headings, 'market potential', and 'potential for the company', with respectively 17 and 22 sub-factors. A rather looser method rating factors was suggested, the 'key' merely defining the end points of a range of seven possible values. For example, if it is required that the factor 'Demand for product' be rated on a scale beginning with 'weak desire' and ending with 'necessity'. Factors could also have been rated 'not known' if this was relevant.

1.2.1 Scoring Models.

The main objective of scoring models is project evaluation. This is required in situations where a choice is necessary. For example, the selection of the best of two alternatives, or the examination of whether the project return exceeds a certain minimum, or threshold level. The use of scoring models is largely confined to projects at their initiation, or immediately post initiation phases, when evaluation in terms of one of the well known financial criteria (Section 1.3) is not possible.

There are two distinct classes of scoring model. The first is a simple extension of the checklist. The factor ratings, or scores, are combined together in a manner prescribed by the model, to form a score that is held to be a measure of the project value or return. The second is the 'profitability' model in which the project return is defined by means of a simple algebraic expression that is related to the financial return of the project.

One of the first scoring models to receive mention in the literature was that of Mottley and Newton (18). The large number of factors contributing to the eventual success or failure of a project were reduced to five:

(1) Promise of success.

(2) Time to completion.

(3) Cost of research.

(4) Strategic need.

(5) Market gain.

Each factor was scored 0, 1, 2, 3 according to whether it was manifest to the degree: poor, unforseeable, fair, or good. The project score was then determined by multiplication of the factor scores, and thus may have taken a series of integer values in the range 0 to 3^5 (i.e. 243).

A more refined method was that proposed by Dean and Nishry (19), who granted the project assessor an additional degree of freedom by requiring weights w_i, to be attached to each factor under consideration. The weights were such that:

$$0 \leq w_i \leq 1 \text{ and } \sum_{i=1}^{n} w_i = 1,$$

where n was the number of factors in the model. Though the authors took the model further, the principle was to give an integer score s_i, in the range 1 to 5, to each factor, and to determine the project score P from the expression:

$$P = \sum_{i=1}^{n} w_i s_i$$

(In the application of the model quoted by Dean and Nishry the number of factors (n) was 36.)

A similar method, though not strictly relevant to the research situation, was suggested by O'Meara (20), who advocated a separate treatment of short term prospects, long term prospects and 'intangibles'. (This paper provides a good example of how a comprehensive frame of reference may be attached to each factor under consideration).

An example of a scoring model, based on profitability, has been devised by Hart (21). The index (reflecting the financial return of the project) was given by:

$I = SPpt/100C$, where

S = peak sales value (£ per annum),

P = net profit on sales before tax (%),

p = probability of R & D success,

t = a discounting timing factor (years),

C = future cost of R & D (£).

The index was thus related to the expected value of future profit per unit of R & D expenditure and was evaluated by awarding scores to each of the factors. A chart was used for this purpose; the Table below presents the scores to be assigned to the factor 'peak sales value'.

Peak sales value (£/annum)	2000	5000	10000	20000	50000	100000	200000
Score	30	70	100	130	170	200	230

Hart arranged for factor scores to be related to the logarithm of factor values. Thus logarithmic interpolation is required to score factor values lying between those given by the chart, and a project score related to the logarithm of the project index may be found by addition and subtraction of factor scores.

Projects are finally grouped into four classes according to project score (see below).

Project score	500 or less	500-550	550-600	600 or more
Project rating	Poor	Fair	Good	Excellent

Though both types of scoring model appear to have been accepted by a number of R & D Departments (22), there are several disadvantages that must also be recognised.

(1) The calculation of a project score will tend to detract from the value of the checklist, as an indicator of the attributes of the emerging system. It might be expected that once a score has been given to the project, it will become the focus of the management's attention.

(2) The methods of combining factor scores together, to form a project score, are often subject to suspicion because none have strong a priori grounds for support. Furthermore it is usual for different scoring schemes to arrange projects into different orders of merit.

(3) A criticism which may be levelled at some of the profitability models (e.g. Harts method) is that it is often more straightforward to make a routine financial assessment than to use the model. (i.e. Simpler to evaluate a criterion, in terms of the basic variables, rather than convert the basic variables into scores and manipulate the scores).

One advantage that scoring models may show over financial evaluation however, is in making allowance for 'intangible' factors. Persons may be prepared to ascribe a score or rating to an important factor, which they might be unwilling to quantify precisely in cash terms. For example Hart, in determining the score to be given to 'net profit on sales' gives weight to:
production know-how, customer's attitude to product, external competition, as well as to marginal cost and capital investment.

The author has made a comparison of some of the implications of employing addition and multiplication as a means of combining the factor scores of scoring models into project scores. This work was based on the Mottley-Newton model (see above) and is presented in Appendix 1.1.

1.3 Financial Criteria and Uncertainty.

When projects have advanced beyond the exploratory stage, and when sufficient financial data has become available, it is usual to evaluate in terms of the costs and benefits that are expected to accrue. For example, if a project is concerned with developing a new product, the relevant data will be the capital investment, the operating cost, the market growth, the selling price, the marketing and promotional costs, and the cost of research. There is clearly some virtue in expressing the project return in terms normally used to assess capital investments, or indeed the performance of the firm as a whole. It is hardly surprising therefore that criteria such as return on capital, payback period, net present value (NPV) and discounted cash flow rate of return (DCF) have been advocated for the evaluation of research projects. These criteria are defined in detail in Appendix 1.

Some related, but less familiar, criteria were presented in a research study sponsored by the American Management Association ((22), pages 62 and 63). Two examples are:

(1) Villiers criterion

Value of project = p (E - R)/C, where

p = Probability of commercial and technical success,

E = Present value of future earnings of the product,

R = Capital required for commercialisation,

C = Cost of the R and D effort on the project.

(2) Pacifico's criterion

Value of project = $p\,SP\sqrt{L}/C$, where

S = Average annual sales volume,

P = Average profit/unit,

L = Life of project in years,

p and C are as for (1) above.

Just as criticisms may be levelled at the methods of combining the factor scores of scoring models, so too criticisms may be levelled at each of the financial criteria. For example, with reference to the criteria introduced above some rather obvious shortcomings are:

(1) Payback period takes no account of the returns that accrue after the breakeven point.

(2) DCF rate of return measures the efficiency of resource conversion, without indicating the magnitude of the profit.

(3) Pacifico's method takes no account of the time value of money.

A strong body of economic opinion have expressed a preference for criteria employing discounted cash flow, and particularly for NPV and

DCF. (For example see Merrett and Sykes (23) or Bierman and Smidt (24)). Cash flow methods provide a realistic means of taking account of the time value of money and of including the effects of the existing system of investment grants and company taxation.

One of the few papers presenting a view not wholly in agreement with that of economists as expressed above is that of Allen and Edgeworth Johnstone (25). On the evidence of a limited experiment (seven research projects were monitored) it was found that DCF rate of return did not prove as useful a predictor of successful projects as did some other criteria. All of these other criteria were related to the geometry of the cumulative cash flow curve; one was payback period and the others were 'equivalent maximum investment period' and 'interest recovery period', which were invented by the authors of the paper. Details of these criteria are given in Appendix 1.

Before leaving criteria it is well to consider more carefully the cost of research. This often appears in evaluation criteria, three examples are provided above by those of Hart, Villiers and Pacifico. The cost that should appear, but which is rarely mentioned, is the opportunity cost. Lipsey ((26), page 248) defines the opportunity cost of using a factor to be the benefit foregone (or opportunity lost) by not using the factor in its best alternative use. Thus if it is company policy to hire research personnel on a long term basis, and there are not enough potentially profitable projects to occupy the whole of the staff then, until the whole staff are so occupied, the opportunity cost of employing staff on new projects is zero. This is because nothing is foregone by transferring staff from unprofitable projects. In other circumstances, if funds for a very promising project have to be withheld, then the opportunity cost of research on the continuing portfolio of projects may be much larger than the costs of the staff involved.

1.3.1 The Examination of Uncertainty.

In the evaluation of research projects the need for a consideration of uncertainty is clear. Evaluation, whether on the basis of a scoring model or a financial criterion, depends upon the assumptions with respect to the future values of variables concerned. Some of these will be under the firms control (e.g. the process to be employed), some will be partly under the firm's control (e.g. operating cost), and some will be largely outside the firm's control (e.g. the price-volume relationship). The writers on decision theory (for example Schlaifer (27)), often express the different future situations in terms of 'decisions' to be taken by the firm, and the 'states of the world' which define the future conditions which may arise.

At this stage it will be helpful to distinguish between states of 'risk', 'uncertainty' and 'ignorance'. (The work of Farrar (28) and Schon (29) is taken as a guide to the following). The 'risk' situation is characterized by knowledge of (a) all the possible futures or outcomes of the project and (b) the probability of occurrence of each outcome. These conditions are the essence of insurance underwriting and often occur in games of chance: cards, dice, roulette, etc.

On the other hand a situation subject to uncertainty is characterized by a lack of complete knowledge of (a) the possible futures or outcomes of the project and (b) the probabilities of their occurrence. With respect to the latter however, it is sometimes assumed that, by comparing the situation with similar situations which have occurred in the past, some subjective estimates of probability can be made. A subjective estimate of probability reflects a person's degree of belief that a specific outcome will occur. The validity of the concept is still a point of contention amongst statisticians. No attempt will be made to present here the arguments for and against. The book by Savage (30) records a collection of views on the problem. A formal procedure for assigning subjective probabilities, based on a 'standard lottery' may be found in Schlaifer's book ((27) page 11). If the situation is such that it is impossible to estimate even subjective probabilities of the various outcomes or futures which might occur, then a state of 'ignorance' (or 'maximum uncertainty': Thiel (31)) is said to exist.

Some writers would argue that the act of assigning probabilities changes the situation from one of uncertainty to one of risk. The convention followed in this thesis will be to assume that all research decisions are taken under conditions of uncertainty, even though, from time to time, subjective probabilities will be assigned to the occurrence of future events.

The simplest way of taking decisions under uncertainty is, of course, to go ahead under the assumption that the most probable outcome will occur. This philosophy is only sound when the expected outcome has a high probability of occurrence. Several methods for assisting management make allowance for uncertainty, or alternatively, for assessing the implications of uncertainty are now discussed:

(1) The risk premium.

The risk premium makes an allowance for uncertainty by demanding that the threshold or minimum level for accepting projects be increased, to balance increased uncertainty. The concept is well established in economic theory, for example Lipsey ((26), page 249) wrote "Business enterprise is often a risky affair..... They (the owners) will not take risks unless they receive a remuneration in return. They must expect to receive a return in excess of what they could have obtained by investing their money in a virtually riskless manner.....".

The risk premium is commonly used in industry today and it is often recommended in the literature. For example Ansoff ((11), page 48), suggests that firms establish three levels of acceptance threshold, corresponding to three different degrees of uncertainty.

Thus a 'risky' project may be expected to show a DCF rate of return of > 30%, whereas only a 10% DCF rate of return might be required when success is assured. (Of course the values chosen will depend on the price of money - 10% might seem a little low at the time of writing.) The great weakness of the approach is that no measurement of the uncertainty is made and thus little guidance on the appropriate premium can be given.

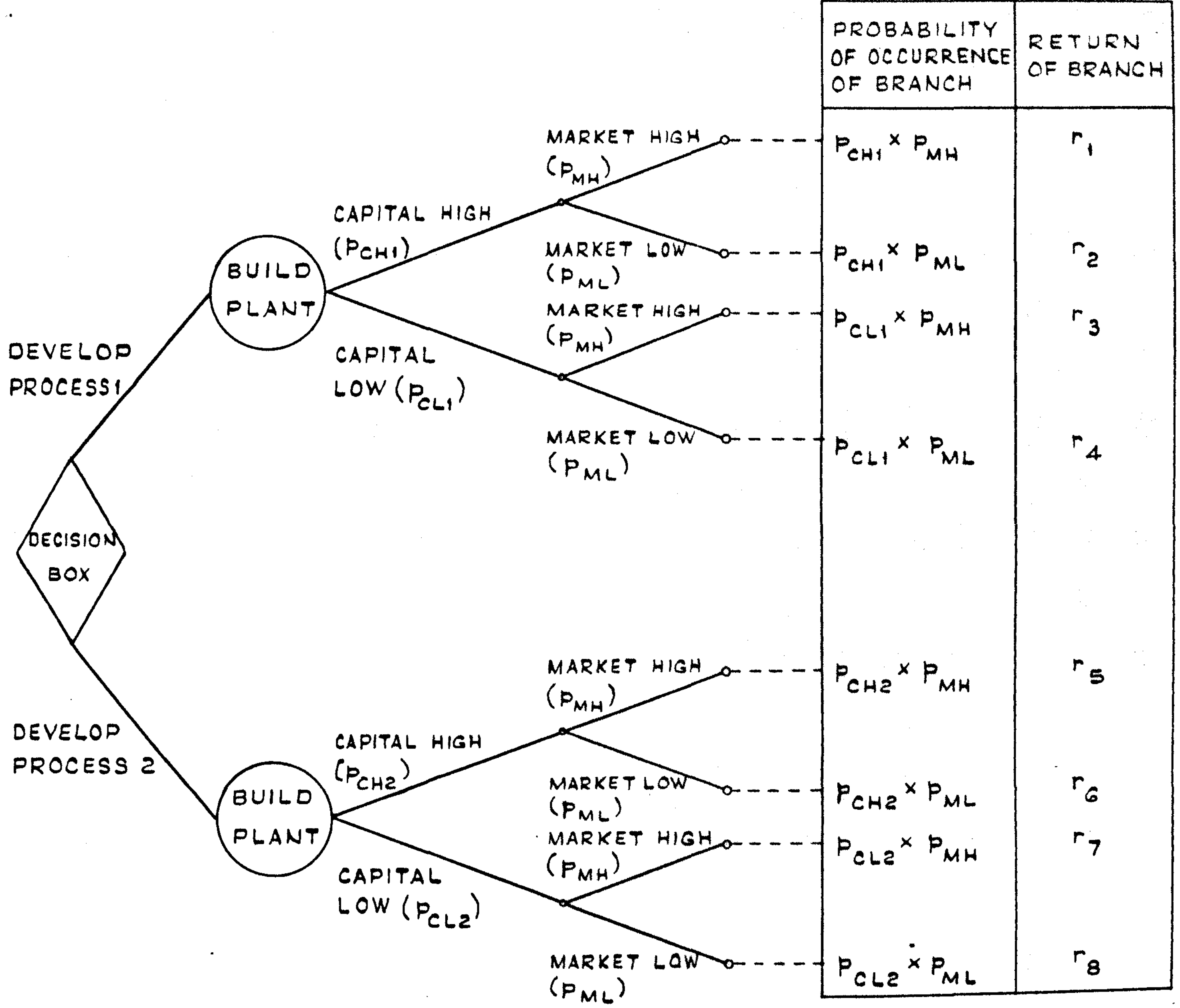
(2) The evaluation of the project return in 'optimistic', 'expected' and 'pessimistic' cases.

This method requires three estimates of each of those variables subject to uncertainty, in the criterion measuring project return. In a new product project in which NPV is the criterion, the variables subject to uncertainty could be: capital cost of plant, variable operating cost, and market volume. The three estimates of capital cost could be £1.3M, £2M and £3M, with the optimistic and pessimistic values corresponding to a 90% confidence interval, and the £2M to the most likely value.

The range of project return is then determined by combining (a) all the optimistic values (b) all the expected values, and (c) all the pessimistic values of the variables. However, as little information on the distribution of the project return across the range is given, the value of the method is somewhat limited. Also the pessimistic-optimistic range can be a rather extreme measure of the uncertainty of the project. If the 90% confidence interval is used to define the optimistic and pessimistic estimates, and several variables are subject to uncertainty, then the chance of the project return lying outside the pessimistic-optimistic range is extremely remote.

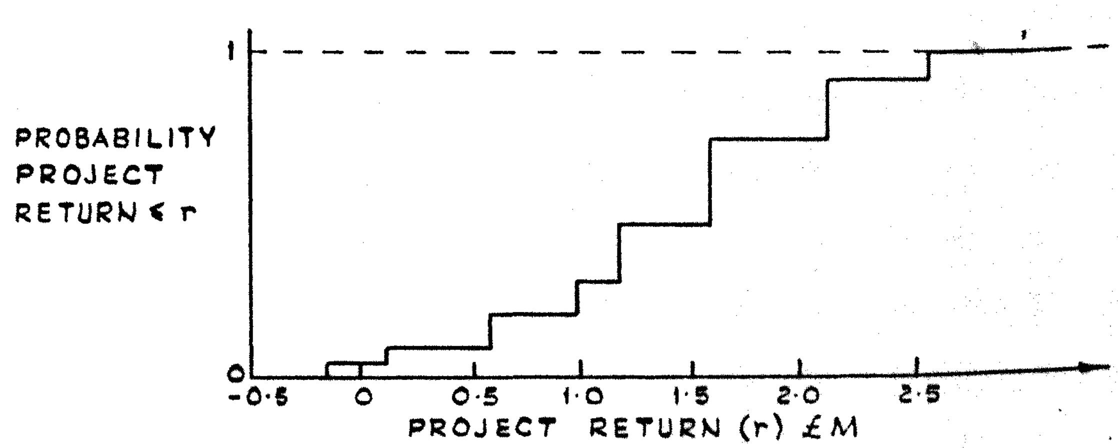
(3) The tree network.

The tree network is an elaboration of (2), the network providing a helpful method of illustrating a number of alternative 'decisions' and 'states of the world', which might arise in the future. Magee (32, 33), was one of the first to report on the virtues of the procedure, and both Raiffa (34) and Schlaifer (35) have written books on the application of decision trees. As an example, suppose that a decision must be taken on a process for manufacture of a new product, and that the capital cost of plant, and the eventual market size, are subject to uncertainty. The network shown in Figure 1.3 may be used to illustrate the decision situation. By assigning probabilities of occurrence to the various capital costs and markets which may arise, and evaluating the return



THE p's ARE SUBJECTIVE PROBABILITIES OF OCCURRENCE OF THE VARIOUS FUTURE SITUATIONS ($p_{CH1} + p_{CL1} = 1$, $p_{CH2} + p_{CL2} = 1$, $p_{MH} + p_{ML} = 1$).

FIGURE 1·3 : DECISION TREE ANALYSIS



A DISTRIBUTION OF THIS FORM MAY BE DRAWN TO PRESENT THE IMPLICATIONS OF EACH OF THE DECISIONS IN THE DECISION TREE.

FIGURE 1·4 : THE DISTRIBUTION OF PROJECT RETURN of each branch of the tree, probability distributions of project return may be built up (Figure 1.4). The decision on which route to develop may then be made on the basis of the distributions. Other advantages are (a) that the standard deviation of a distribution may be used as a measure of the uncertainty of the project return and (b) that probalistic statements concerning the project return may be made. For example, the probability of a return > £1M = 0.8, or the probability of a return > £2.5M = 0.1 (Figure 1.4). The method provides, therefore, a solution to some of the shortcomings raised in (2), and if required may handle more complex situations involving more decisions and more states of the world. A rather obvious elaboration of Figure 1.3, would be to consider further decisions at successive points in time. This step can be very helpful by highlighting 'critical', or 'risky', situations well in advance.

On the other hand, even though telescoping is sometimes possible, increased complexity can severely reduce the inherent simplicity of the method by increasing the number of alternative situations that must be considered. Even routine research projects can give rise to very complex networks. For example, if six variables are subject to uncertainty, and just two levels of each are considered adequate to allow for the uncertainty, then 2^6 (i.e. 64) distinct branches are possible.

(4) Risk Analysis*

This is a computer based technique that may be used to determine a distribution of the project return. The method is generally attributed to Hertz (36). The first step is to express the uncertainty in each of the basic variables (in the financial criterion), in terms of probability distributions. Monte Carlo simulation is then used to generate a distribution of the project return. One simulation consists of (a) sampling a value from each of the above mentioned distributions (this defines a possible future state of the world), and (b) evaluating the associated project return. By making a large number of simulations a distribution of the project return may be determined, the more simulations the closer the calculated distribution will approximate to the theoretical distribution implied by the probability distributions of the basic variables. Though risk analysis is logically rigorous, it must be recognised that the results can only be as good as the subjective estimates of the basic distributions. As it is well known that such estimates must normally be treated with caution, then so too the distribution of project return must also be treated with caution. (This also applies to the results of methods 2 and 3 above). A computer programme written by the author to perform risk analysis calculations is described in Section 3.5.

A method of assessing the implications of uncertainty, which makes no demands for estimates of subjective probability has been proposed by Allen (37). This method is based on Shackle's 'credibility' theory (38). However, at the moment, the problems of application

*There is some confusion concerning the name 'Risk Analysis', since the technique is normally applied under conditions of uncertainty. Presumably the inventor of the name belonged to the school that hold that the assigning of probabilities converts a situation from one of uncertainty to one of risk.

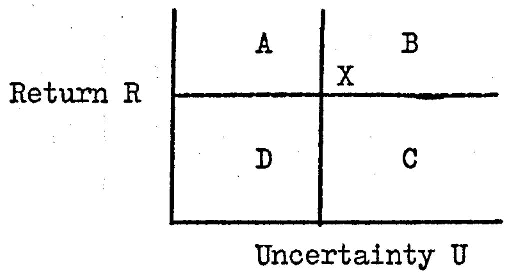
appear to be just as great (if not greater) than those associated with subjective probability.

1.4 Project Selection.

Project selection is the natural sequel to the evaluation of a number of alternative courses of action. It may involve the selection of a set of projects from a group, or at a lower level, the selection of one of a number of different project development strategies. If a single criterion could adequately reflect the value of a project, or alternative, then selection would be trivial; the alternatives could be assembled into an order of merit that could be used as a basis for decision.

In the section 1.3 it was suggested that, because of uncertainty, it is helpful to discuss the project return in terms of a distribution of values. The decision situation now becomes more complex.

Figure 1.5



For example, suppose alternative X offers a return R and an uncertainty U (defined as the standard deviation of the distribution of R). Then clearly alternative X dominates projects in quadrant C (since alternatives in this quadrant have a return $<$ R and an uncertainty $>$ U). Similarly alternative X would be dominated by projects in quadrant A. But without a function 'trading-off' return and uncertainty, there is no means of positioning alternative X in a list of alternatives belonging to quadrants B and D.

1.4.1 Decision Theory.

The traditional theory of decision or choice under uncertainty may be found in the books of Schlaifer ((27), page 3), and Chernoff and Moses (39). The first step is to draw up a 'pay-off' matrix (see below).

Figure 1.6

States of the World.

		s_1	s_j	s_m
	d_1	a_{11}	a_{1j}	a_{1m}
Decisions	d_i	a_{i1}	a_{ij}	a_{im}
	d_n	a_{n1}	a_{nj}	a_{nm}

The rows of the matrix ennumerate the various decisions which may be taken, and the columns the future states of the world which may emerge. The elements define the pay-off or return associated with each decision and state of the world.

If the elements of one of the rows dominate the corresponding elements of all the other rows, then the 'best' decision is clear.

If this is not the case however, then two quite distinct approaches may be taken:

(1) The Game Theory Approach.

The basic assumption is that information excludes knowledge of the probabilities of occurrence of the various possible states of the world and that choice must be made on the basis of the pay-off matrix alone. Three rules or criteria for decision are often suggested (for example see Farrar op. cit. page 4):

Maximax: Choose the decision that offers prospects of the highest possible return.

Maximin: Choose the decision that ensures that the lowest possible return is maximised. (There is a lowest return for each decision).

Minimax: Choose the decision that minimises the maximum 'regret'. The regret (for state of the world s and decision d) is the difference between the project return under these circumstances, and the best return (for any of the decisions) which may be obtained, given state of the world s.

None of these criteria is wholly satisfactory. The first two represent rather extreme points of view: Maximax is the philosophy of the inveterate gambler who is drawn to the high returns without regard to the possible losses that might also be incurred. Conversely, maximin is the rule of the pessimist or cautious man who is concerned only with minimising his possible losses, without regard to the opportunities thereby forgone. Minimax is a compromise, though as Adelson (40) colourfully points out it is subject to some 'psychotic' tendencies. If, for example, minimax is used to define the 'best' of a set of alternative decisions and a member of the set (not the 'best') is removed, then it is possible for the criterion to define a different decision to be the 'best' of the sub-set. A point tending to reduce the value of this approach to choice, in research situations, is the assumption that there is no information concerning the probabilities of occurrence of the various possible states of the world. This is rarely the case, as usually research managers have wide experience, and would wish to take account of this, in reaching their decisions.

(2) The Statistical Decision Theory Approach.

This approach requires probabilities of occurrence (p_j) to be assigned to each of the states of the world in the pay-off matrix. It thus takes account of the decision maker's judgment, and to this extent, is a 'subjective' approach to choice (the game theory approach may be termed 'objective'). The expected value of each decision $\sum_{j=1}^{m} a_{ij}p_j$ (see Figure 1.6) is then employed as a criterion for arranging the decisions into an order of merit. This approach is probably the best established method for advising on the decision to be taken under conditions of uncertainty. It is equivalent to using the mean value of a distribution of project return (from either a decision tree analysis or a risk analysis) as the criterion for decision.

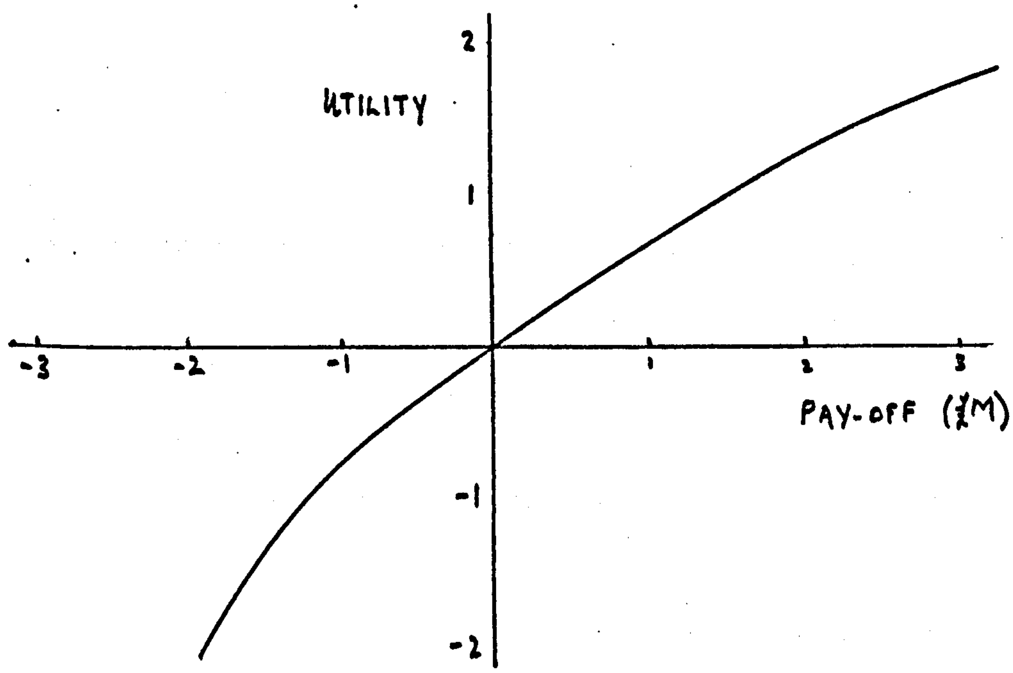
If the probability of occurrence of a future state of the world is required at successive points in time, then Bayes theorem (see Morris (41) pages 30 to 39) provides a means of revising probability estimates in the light of new information, this procedure is sometimes called the 'Bayesian approach'.

An important disadvantage of the 'statistical' approach to decision is that no account is taken of the range of possible returns that might occur if a particular decision is taken. This is most serious if, at the lower end of the range, losses are large enough to place the future of the firm in jeopardy. In these circumstances, it has been suggested by Adelson (op.cit.) and Green (42) that the value of the money scale is non-linear. Cramerand Smith (43) make the point in the following way:

"While £100 may well be spent on a 20% chance of gaining £1000, a £100,000 expenditure might well be rejected, even if it were viewed as leading to a £1000,000 pay-off with a 20% chance of success".

The concept of 'utility' has been suggested as a means of overcoming the problem. In this context, utility is viewed in the manner suggested by von Neumann and Morgenstern (44): as a measure of the decision taker's attitude to risk, rather than as the classical economist's measure of an individual's (or household's) strength of desire for a commodity. By subjecting the decision taker to a series of hypothetical risk situations, a utility curve relating money value to utility may be constructed. The papers by Adelson, Green, and Cramer and Smith explain the procedure in detail, and present utility curves (those of the latter two papers were derived experimentally). Each of the curves took a form similar to that shown in the Figure below.

Figure 1.7



(The curve above shows that over the range - £1M to +£2.5M the value of money is comparatively linear, but that losses of greater than £1M are not balanced by equivalent gains).

The utility curve enables the pay-off matrix (a_{ij}) to be converted to a utility matrix (u_{ij}). The expected utility $(\sum_{i=1}^{m} u_{ij}p_j)$ of each decision, may then be used as the criterion of choice. Though the method is satisfying in theory, and has received a good deal of attention in the literature, there is little evidence of its use in practical situations. This is not surprising since the derivation of the utility curve is difficult; moreover as the fortunes of the firm change with time then so too, it must be expected that the utility curve will change. In situations where it is thought that the nonlinearity of the money scale must be considered then probably the best approach will be for the analyst to avoid the question of choice, and to content himself with presenting the management team with a rigorous analysis of the implications, of each of the alternative decisions. (This is the substance of the view expressed by Green (op.cit.) in his conclusion).

Amongst the other methods of ordering projects, or alternatives, for purposes of selection are the 'certainty equivalent' and 'variable discounting'. However, neither of these methods has received sufficient attention to justify detailed comment. The philosophy of the certainty equivalent is discussed in Farrar ((28), page 11). It is a measure of the project return which takes account of the uncertainty of the situation, and is usually expressed as a function of (a) the expected return and (b) the standard deviation of the return. For example, Cramer and Smith (op.cit.) describe the derivation of the certainty equivalent given by:

$$U = \mu - k\sigma^{a} I^{b},$$

where

U: certainty equivalent,

μ; expected project return,

σ: the standard deviation of the project return,

I: % of the available funds in the project,

a, b, k: are constants.

Variable discounting is a particular form of certainty equivalent in which the discount rate is increased by an amount which is related to the uncertainty of the situation. For example Steindl (45) proposed the rate $r_o + A(T)$, where r_o is the 'risk-free' discount rate and A(T) is dependent on the uncertainty of the alternative.

1.4.2 Portfolio Methods.

In section 1.4, the problem of choice was assumed to rest only on the returns and uncertainties of each of the alternative project strategies, or projects under consideration. No attention was paid to the wider issues:

(1) Are there sufficient resources to undertake the project?

(2) Is it necessary or helpful to reschedule?

(3) What is the effect of the project on the return (and uncertainty) of the department as a whole?

Portfolio methods take account of such wider issues by considering projects as members of an interactive group. The portfolio could include projects in a specific area of research, or more ambitiously, could include all the projects in the research department. The aim of these methods is to point to the allocation of resources between projects that achieves the objectives of the portfolio in the most effective manner. At the same time it is usual for account to be taken of interactions between projects, and the constraints on the resources that may be committed.

One of the first papers in the field was that of Asher (46) who used a method, based on linear programming (LP) to maximise the expected NPV of a group of projects, subject to constraints on the availability of specialized staff. (Asher was a member of the staff of a pharmaceutical laboratory). A similar method was reported by Chilcott (47) who maximised a department 'benefit' (the criterion was not defined) subject to constraints on capital, manpower and specialized equipment.

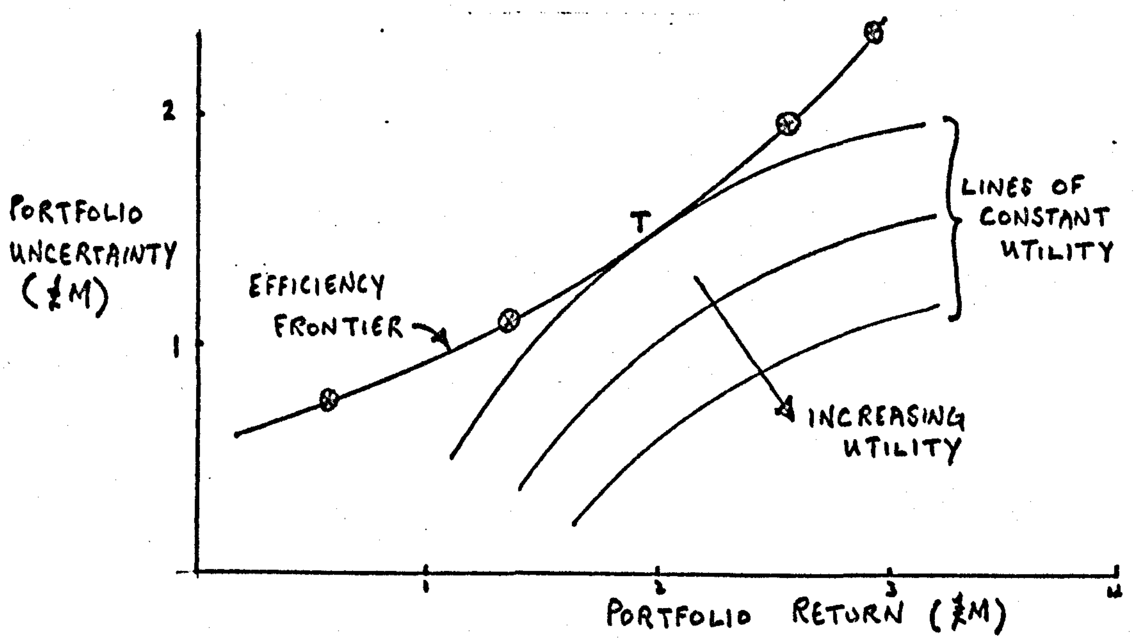
The most recent approach is probably that of Bell et.al. (48) who once again used LP to maximise the expected NPV of a set of projects. (These authors also investigated the use of integer programming (IP), to avoid the selection of fractions of projects, but found that the additional computing costs were not justified). A most flexible input to the model was developed; several versions of each project corresponding to different work schedules may be defined. Constraints may be placed on variety of different resources: capital, specialized equipment, manpower, and importantly on the variance (the square of standard deviation) of the 'optimal' portfolio. There is also provision for:

(1) Limited transfer between different classes of staff. For example some of the chemists may be allowed to do physicist's work.

(2) 'Fill-in' projects. A proportion of the future resource allocation may be set aside for projects not yet begun (or thought of).

The inclusion of the constraint on the variance of the portfolio enables an 'efficiency frontier' to be established by maximising the portfolio return for different levels of portfolio uncertainty. (Assuming that the portfolio uncertainty is defined as the standard deviation of the portfolio return). The concept of the 'efficiency frontier' was introduced by Markowitz (49). The figure below illustrates the point that generally increased return may only be bought at the expense of increased uncertainty.

Figure 1.8



Markowitz, who was dealing with security investments, suggested that T (Figure 1.8) was the optimum point on the efficiency frontier. (Where T defined the point of tangential intersection of the efficiency frontier and a set of lines of constant utility, which describe the portfolio manager's attitude to risk.) Bell et.al. (op.cit.) adopted a more practical approach in the research situation, and suggest that the management team be presented with the efficiency frontier for their inspection, and decision, on the level of uncertainty to be accepted.

Though portfolio methods have received considerable attention in the literature, there is a major problem still to be overcome before their general implementation: that of convincing the departmental management that the allocation of resources derived by the model is to the advantage of the firm. The question of R & D objectives arises immediately. The maximisation of a financial criterion such as NPV, or benefit/cost ratio, is almost mandatory in portfolio methods.

But this invites the criticism that there are a variety of other R & D objectives that are not included in the model.

A more serious criticism of some portfolio methods however, is that they seem to be unrealistic in the research situation in the chemical industry. Experience gained during the present research suggested that portfolio management was by accretion to, rejection from, and shaping of, the existing set of on-going projects. Furthermore the process takes place continuously over time rather than as a one-off operation at periodic intervals as assumed by the portfolio models.

1.5 Project Control.

Project control is concerned with the achievement of the project's objectives within the permitted budget and time schedule. The key is sound forward planning of work and frequent feedback of information to ensure an awareness of progress and changes in circumstances. The methodology of project control in research may be divided into two main areas concentrating on:

(1) Techniques for planning and costing future research (which may also be used to monitor progress).

(2) Practical control systems. (Mainly of an industrial origin, these papers usually describe how information derived from (1) (and other sources) is presented to management.)

The simplest of the planning techniques is the 'Bar' or 'Gantt' chart; an example is provided in Figure 1.9. The activities to be completed are listed, and the expected starting times and durations of each are indicated by bars on the adjacent time scale. By

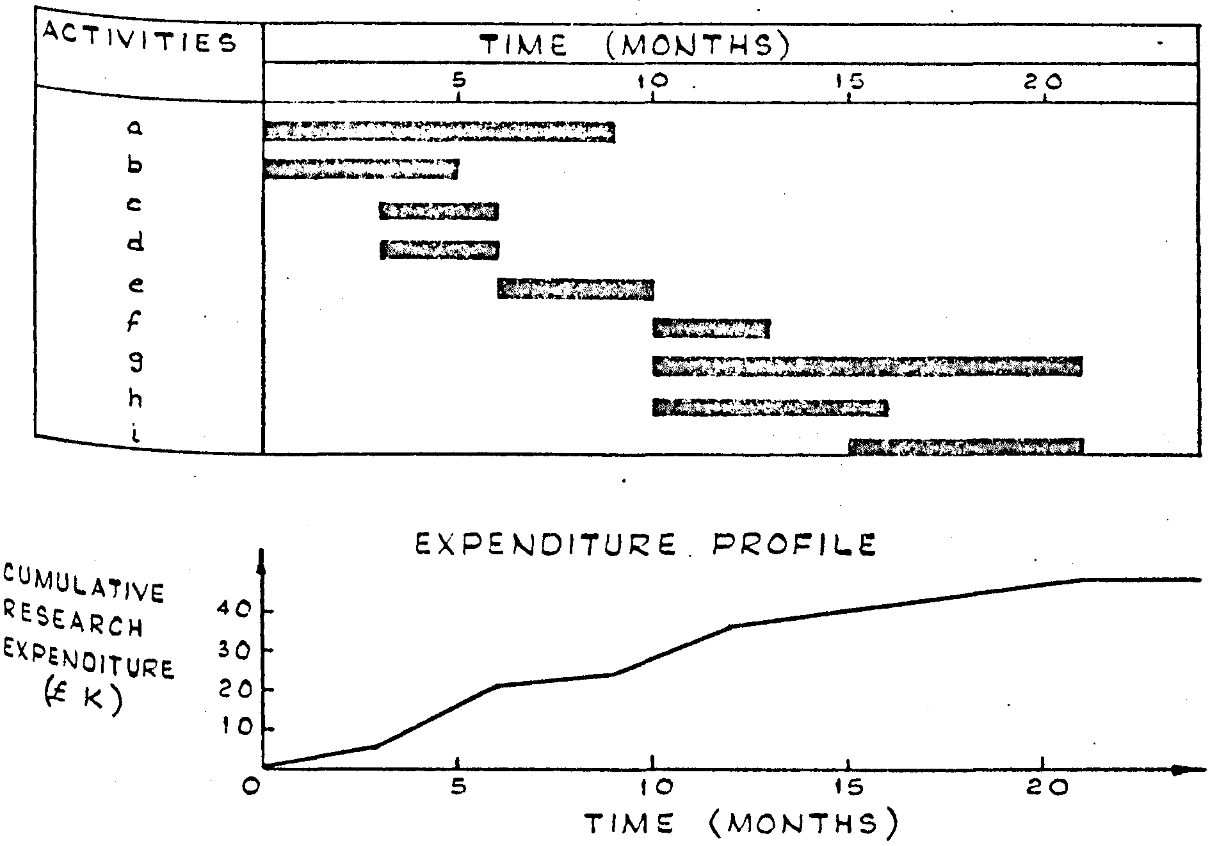
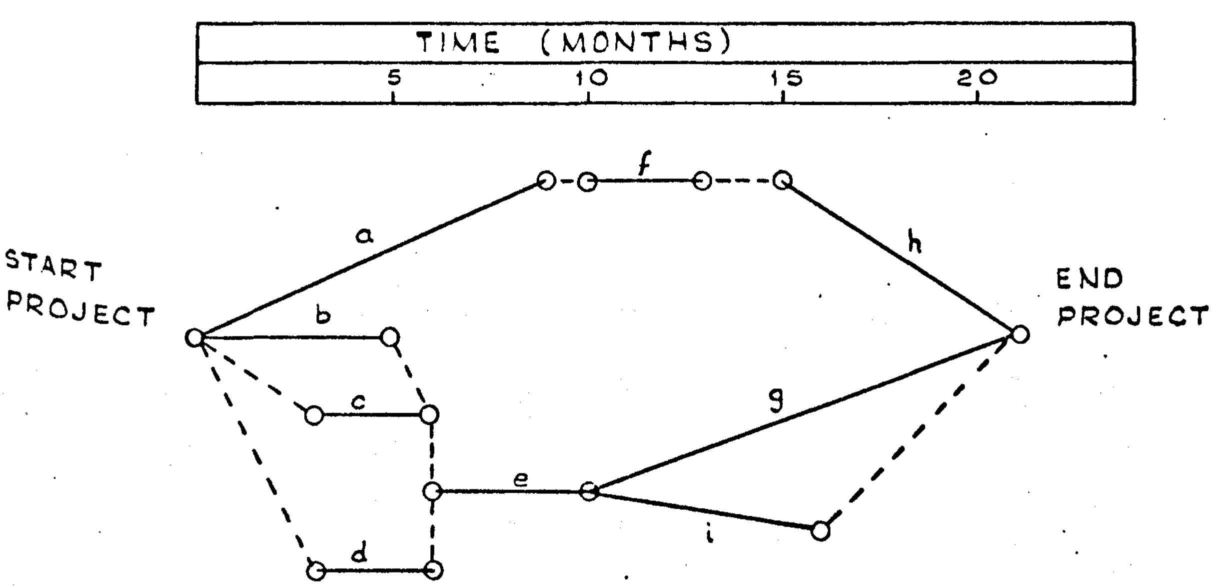


FIGURE 1·9 : THE GANTT CHART



(THE DASHED LINES INDICATE A LOGICAL DEPENDENCE)

FIGURE 1·10 : A NETWORK APPROACH

assigning unit costs to each of the activities, the bar chart may be used as a basis for constructing the profile of research expenditure against time.

The bar chart, however, is inadequate to cope with the planning of large and complex projects. For this task 'networking' techniques are often recommended; the two most well known techniques are CPM (critical path method), and PERT (project evaluation and review technique). These methods are similar both in principle and operation - the interested reader is referred to a specialist text on the subject, for example, Battersby (50) or Lock (51).

Though the differences between the bar chart and the network are not great, the development of the latter was an important advance. Figure 1.10 illustrates how the bar chart of Figure 1.9 may be presented as a network. It is readily apparent that the logical structure of the network enables the order in which activities may be started to be more explicitly defined. For example, activity e may only be started after activities b, c and d are complete.

The network approach also permits further analysis (Battersby and Lock op.cit.), for example:

(1) Determinations of a critical path through the network (this is a path that defines the minimum completion time of the project). If (M_i) is the set of minimum completion times of each path through the network, then the critical path is given by the maximum of the set.

(2) Determination of profiles of expenditure against time. (This may be extended to include the re-scheduling of activities to

ensure budget constraints are maintained.)

(3) Determination of the expected completion time of the project and the associated variance. (This is a facility which distinguishes PERT from CPM. The former takes account of uncertainty in the estimation of activity times by requiring three time estimates: optimistic, expected and pessimistic.)

As the number of activities in networks increase, it becomes essential to use a computer for data processing. Indeed, from conception, the PERT system was designed as a computer based technique, capable of handling several thousand activities. (PERT was devised for the purpose of controlling the R & D leading to the Polaris missile; the programme of work is described in the paper by Malcolm et.al. (52).)

A shortcoming of the CPM and PERT methods, in their basic form, is the requirement that all activities in the network must be completed. A number of variations more appropriate to the research situation have since been proposed. Three examples are:

(1) Eisner (53) who suggested 'branching' networks, with the assumption that future work need not involve all the branches of the network.

(2) Hart and Rumens (54) who suggested a procedure for recycling some of the activities.

(3) Baines, Bradbury and Suckling ((5), page 215) who suggested a system of linked satellite networks as a means of presenting recycling activities.

Despite these improvements networking in research has never gained the acceptance or the respect it commands in other disciplines -

for example civil engineering construction. The most carefully formulated research networks often become out of date before even one quarter of the time period has elapsed. Uncertainty is the most important factor. Research is subject to a high level of uncertainty, and the greater the uncertainty the less precise the conclusions that may be drawn from the network. This has led to the comment that the most valuable part of networking research projects is the formulation step. Of course the comment contains more than an element of truth but even this is no mean achievement. The philosophy of those in research wishing to take advantage of networks must be to accept (a) that networks once formulated are not the last word, they are simply a means of presenting the implications of research, given present knowledge, and (b) that changes to the network, sometimes frequent, are almost inevitable.

Two of the papers describing systems of project control in use in industry are those of Baker and Smith (55) and Soistman (56). Baker and Smith described an experimental procedure of project control designed to meet the needs of the Unilever Research Laboratories. At initiation, the project and (if possible) a criterion of success, are defined. Next, a project plan is drawn up and a cost estimate prepared - a networking approach is suggested for this stage. Finally two indices are assigned to the project:

(1) The queue index (QI). This is an assessment ($0 \leqslant QI \leqslant 100$) of the importance of the project, relative to other projects in the department. It is assumed that at any time the QI's will be distributed about a median of 50.

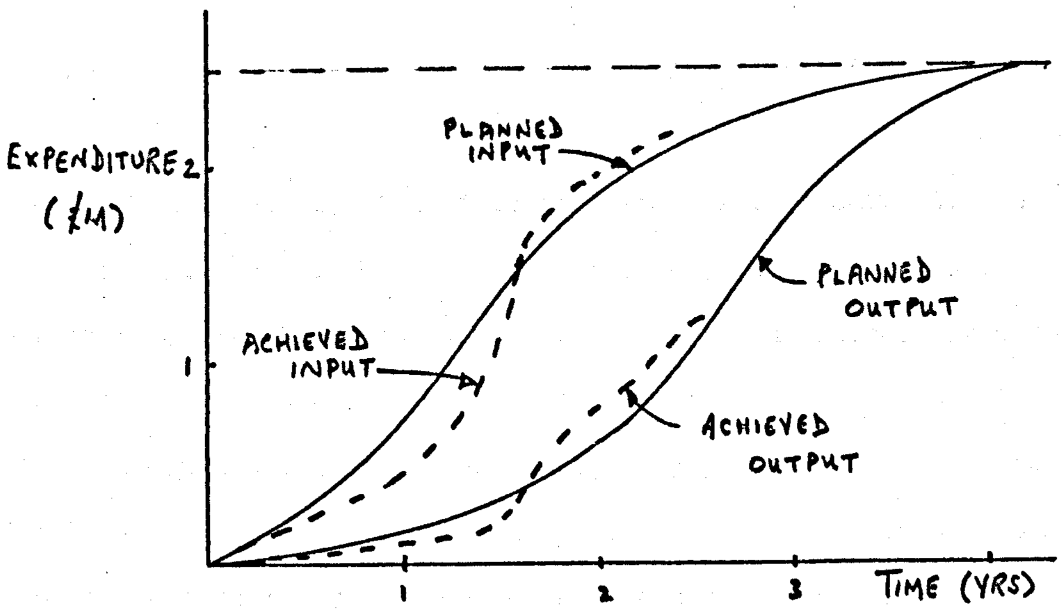
(2) The technical feasibility index (TFI). This is a number ($0 \leqslant TFI \leqslant 1$) that is related to the technical problems remaining to be overcome. It is given a starting value of 0.5 and is

increased or decreased according to progress towards technological objectives.

At four weekly intervals reports on expected completion date, expected cost, TFI and rate determining factor (RDF) are made. (The RDF is the resource input to the project that controls progress.) The occurrence of (a) significant increases in forecasts of completion times or costs, or (b) decreases in TFI, alert management to the need for action. In this event, the RDF may suggest the area where effort is required. At 12 weekly intervals management is provided with an overall project assessement. Recently a paper by Rainbow (57) has commented on experience of operating this system. It was found that whilst the bulk of the data provided the basis of an adequate system of project control, the TFI and QI indices (revised at twelve weekly intervals) proved rather disappointing. The most important reasons for this appear to have been the difficulty of (a) getting the analysts concept of the indices across to management, and (b) persuading management to use the indices in the spirit in which they were intended.

Soistman's paper discussed a method of project control used in the Martin-Marietta company. A bar chart is used to plan the project and to construct a profile showing the input of resources as a function of time. A second profile of output of research is also constructed by attaching cash values to the achievement of 'milestone' events. The method of making this step was not disclosed, but the cash value of the output, at the end of the project is set equal to the cash value of the input. The figure below illustrates the input - output profiles.

Figure 1.11



By monitoring the achieved cash input and output values against plan, Soistman claimed that effective control can be maintained; to support this (op.cit. page 21) he states that for Martin-Marietta projects in 1965, the overall deviation from plan was $< 3\%$.

Criticisms which may be levelled at both of the above systems are:

(1) There is little reference to uncertainty in the forecast costs or completion times.

(2) The benefits of the research receive little attention.

It must be borne in mind, however, that the designers of the systems have been constrained to meet the special requirements of their employers. Their aim was not to develop a general system of project control (though points of general interest do emerge). Many of the papers on project control (for example Soistman's) are concerned with 'contract research' in which the sponsor guarantees the research laboratory a return, when a certain specification has been achieved.

It is not surprising that the reqirements of these organisations are quite different from those of non-contract laboratories such as ICI's.

The former class concentrate on achieving a well defined criterion of success, within the time and cost budgeted for. If success is achieved then income is assured in the terms of the contract. On the other hand, in the chemical industry, the income from research is often strongly linked to success in the related business area. It is of little consolation to develop a new process to a product if the product has been rendered obsolete by competition. Project control systems in R & D departments such as Mond Division's must therefore include reference to the prospects of the business areas related to the project.

Chapter 2.

THE DEVELOPMENT OF A PROJECT EVALUATION AND CONTROL SCHEME: THE STARTING BASE.

The analysis presented in Chapter 1 revealed some of the strengths and weaknesses of existing methods for project evaluation and control. The numerical methods of financial evaluation, the use of discounting, the attempts to deal with uncertainty, are of great assistance in the research context and represent a significant advance on uninformed judgment. On the other hand, there remain many aspects of evaluation and control which must also be taken into account but which cannot at present be treated in quantitative cash terms. Examples are: long term objectives, exploitation of existing strengths and the social effects of innovation. Some over-enthusiasm for numerical procedures, to the neglect of non-quantified inputs to decisions, has led to disappointment and a sharp retreat in some industrial departments from formal procedures as guides to the evaluation and control of research projects.

The author was fortunate in having the opportunity of working in a Division of ICI, in which the significance of unquantified inputs to resource allocation decisions was well recognised, but which was at the same time, well equipped to take advantage of the latest statistical and operational research techniques. It has been by work on current issues, and frequent and continuing interaction with project management, that the systems described in the following Chapters have been devised. Though an effort was made to retain as much generality as was possible in the methods formulated, a bias

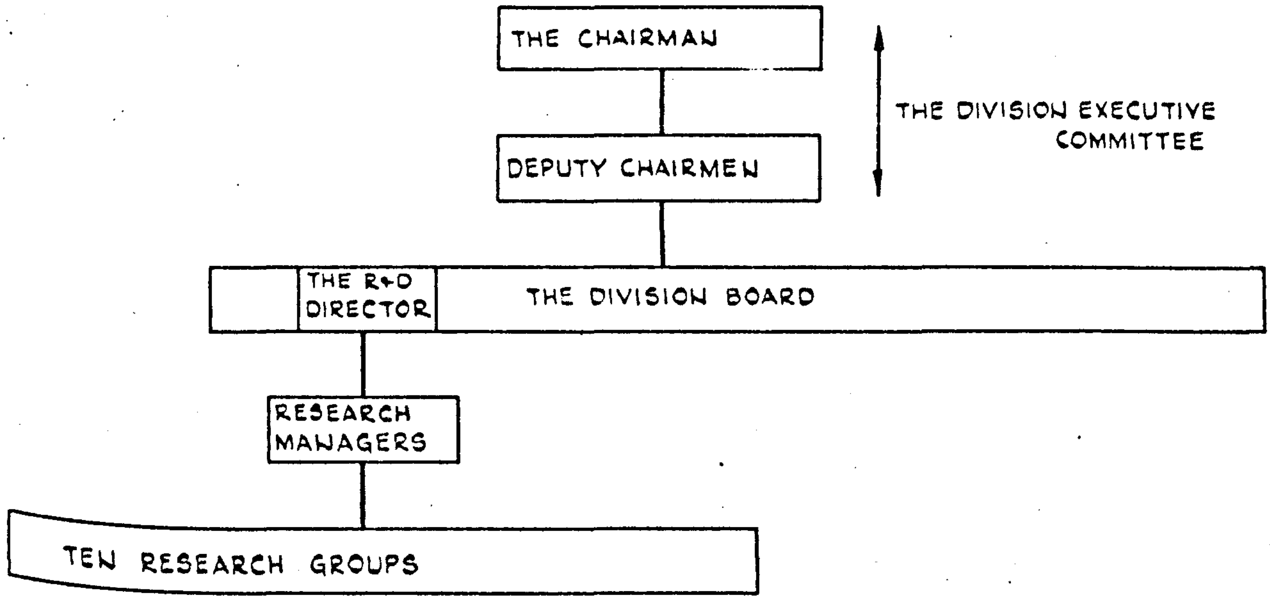


FIGURE 2·1 THE ORGANISATIONAL STRUCTURE OF R&D WITHIN MOND DIVISION

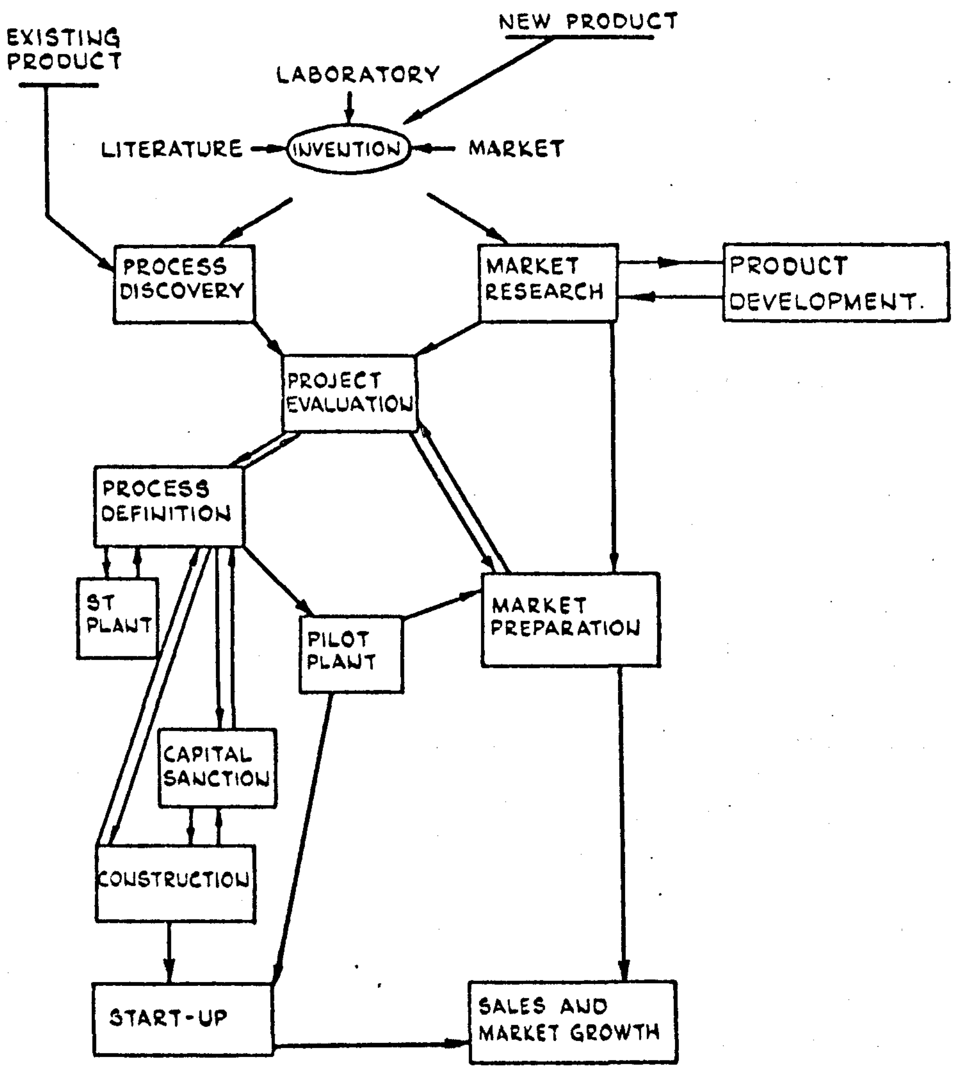


FIGURE 2·2 PROFILE OF A DEVELOPMENT PRODUCT towards research in the chemical industry remains. In order to give a better understanding of the approach taken, the opening section of the chapter is devoted to the organisation of R & D in Mond Division of ICI where the study was made. The remainder of the chapter describes a past research project that is used to highlight some difficulties met in the evaluation and control of research projects.

2.1 The present organisational structure and system of control.

Figure 2.1 shows the organisational structure of the Mond Division R & D Department, in relation to the top management of the Division. The Department is headed by the Research and Development Director who is a member of the Division Board and who is assisted by two Research Managers. Several hundred research scientists and their supporting staff are employed, with expertise that extends over a wide range of disciplines. (Though chemistry predominates, chemical engineering, physics, mathematics, biology and economics are also represented.) The work of the department is divided between ten research groups, each of which might have about fifteen projects underway at any one time. Day-to-day control over projects is the responsibility of Research Leaders who report to Group Managers. The work undertaken by the department covers the whole of the field normally associated with research in the chemical industry. The most important activities are:

(1) Exploratory and background research, in fields of interest to the Division.

(2) Improvement of the existing processes of the Division.

(3) Development of new processes for existing products.

(4) Development of new products and processes for their manufacture.

(5) The operation of small scale plants (a) for obtaining the technical

information associated with the scale-up of new processes and design of new plant, and (b) for production of small quantities of new products for market development. (Work in this area is an extension of that in (3) and (4)).

The methods to be described later are particularly concerned with work in categories (3), (4) and (5) above, where a large proportion of the research budget is spent.

2.1.1. The Stages of New Product or New Process Research.

The most important features of new product and new process research projects have been described in a paper by Bradbury, Rose and Suckling (58). A model of the innovation process developed from this paper is shown in Figure 2.2. Important points of this diagram are the parallel attack of technical and market research, and the central role of project evaluation. New product projects are shown to begin with an 'invention' step that may be the response to stimuli arising in the market, literature, or laboratory. Research on new processes for existing products begins at a later stage called 'process discovery'. As Bradbury et.al. suggest, this step may commence in the office, with the generation of a number of possible routes. Most of these will be eliminated by crude screening on chemical feasibility, raw materials costs, etc. Those routes passing the crude screen pass on to the next stage of process discovery: laboratory screening.

Process definition is reserved for the few routes that pass further screens and show promise of meeting technological and economic criteria. The object at the process definition stage of innovation is to investigate in detail the problems of transforming what is a promising process at laboratory scale into a process that will perform efficiently at plant scale and satisfy the requirements and regulations with respect to hazards, effluents, control systems, product quality, etc. It is necessary therefore, to investigate the characteristics of the process under a variety of operating conditions. Design of experiments, and computer based mathematical models, have played an important part in this phase of work in recent years. Though process definition may begin in the laboratory, it is usual for the final stages to be completed at semi-technical scale. This involves building plant, or parts of plant, at larger than laboratory scale to obtain information for costing and design of the full-scale plant, and for its subsequent operation.

New product work will also require product development in parallel with market research and, later, market preparation. Product development is likely to involve major and minor changes in product specification and formulation to meet customer's requirements. Market preparation will be concerned with problems of: customer identification, the provision of suitable demonstrations, the compatibility of the new product with customers processing equipment. For these purposes supplies of product are required. To meet this need and to maintain supply until a full-scale plant is in operation, it is usually necessary to build a 'pilot plant'. The differences between semi-technical and pilot plants lie in the emphasis of operation; information generation is the objective of the former, and production of the latter. The two functions may be combined on the same plant, but there are risks in so doing, of failing to produce both information and product.

Active research will continue during the early design stage to refine design information, to deal with problems uncovered in design work, and to upgrade process models for effective process operation. After plant construction comes commissioning and start-up when R & D personnel are likely to join the works team.

The paper by Bradbury et.al. (op.cit.) deals in depth with each of the above stages in research.

2.1.2 Project Control Systems.

There is usually a variety of components in the systems of project control in R & D departments; some were discussed in Section 1.5 of the previous Chapter. They range from informal contact between the research worker at the bench and senior management, to periodic reports, to project meetings, to formal reports on the project's standing. An important part of the system at Mond Division as far as top management are concerned, is the research expenditure memorandum (REM). This is required for all projects with annual expenditures above a well-defined minimum level.

The REM is a request by the project manager for funds to cover the costs of the next phase of research. For example, an REM might cover the cost of some speculative work aimed at discovering a new process. If this were successful then another REM would have to be prepared, submitted, and sanctioned, to obtain funds for the next phase of research, some process definition perhaps. The REM is a short document of about three or four pages in length. The format is not rigorously defined, but it is usual to comment upon:

(1) The type of research envisaged (process improvement, new product etc).

(2) The duration of the work (usually 12 to 18 months) and the manpower required.

(3) The sum requested, in terms of capital and revenue.

(4) The amount of capital and revenue previously spent.

(5) The background to the project and the present state of knowledge about it.

(6) The objectives of the work proposed.

(7) The commercial prospects of the overall project.

(8) The patent position.

The authority for sanctioning REM's depends on the amount requested. Expenditures, such as those to cover laboratory work in process discovery, may be within the permitted limit of the R & D director. Larger amounts such as those involving, perhaps semi-technical or pilot plants would normally require the approval of the Division Executive. At a rather lower level, control is exercised by means of regular progress reports, and three-monthly project meetings to consider the achievement of intermediate objectives. Day to day control is exercised by regular contact between the project manager and those undertaking the research.

2.2 A past research project: Project E.

A number of difficulties of project evaluation and control were identified by studying past research projects. One of these (project E) is now described to show how the simple model of Bradbury et.al. fits the practical situation, and to provide illustrations of some of the important points in project evaluation and control. The aim of the project was to secure the supply of an intermediate. At the time research was started, it was believed that within a period of three to four years, Mond Division's demand for the intermediate would exceed the world supply. If this occurred then an important part of the business would be threatened. The alternatives were to contract for further supplies, to licence a process, or to develop a new process. It seemed likely that the Division would be able to develop a new process to the intermediate that would not only secure supply but also offer considerable savings over the other alternatives. Furthermore there were other bonuses to be obtained:

(1) Control over the supply of the intermediate would lie wholly within ICI.

(2) A deterrent would be placed in the path of competitors wishing to enter the market for the final product. (Since the amount of the intermediate produced on the open market would continue to restrict widespread exploitation).

The important features of the project are shown in the bar-chart (Figure 2.3). This adds a time scale, and research expenditure profiles, to the project development network of Figure 2.2. The diamonds in the process evaluation activity indicate points at which the project was evaluated for further funding and the arrows linking the diamonds with process and market research illustrate the dependence of evaluation on both of these activities. The arrows connecting the semi-technical work of routes 2, 3 and 4 show that this work was co-ordinated, and run on the same semi-technical plant. (The increases in capital expenditure in years 5 and 6 (see Figure 2.3) were therefore to cover the cost of modification, rather than the cost of new plant). It is clear that over the first five years roughly equal amounts were spent

FIGURE 2·3: NETWORK OF PROJECT E.

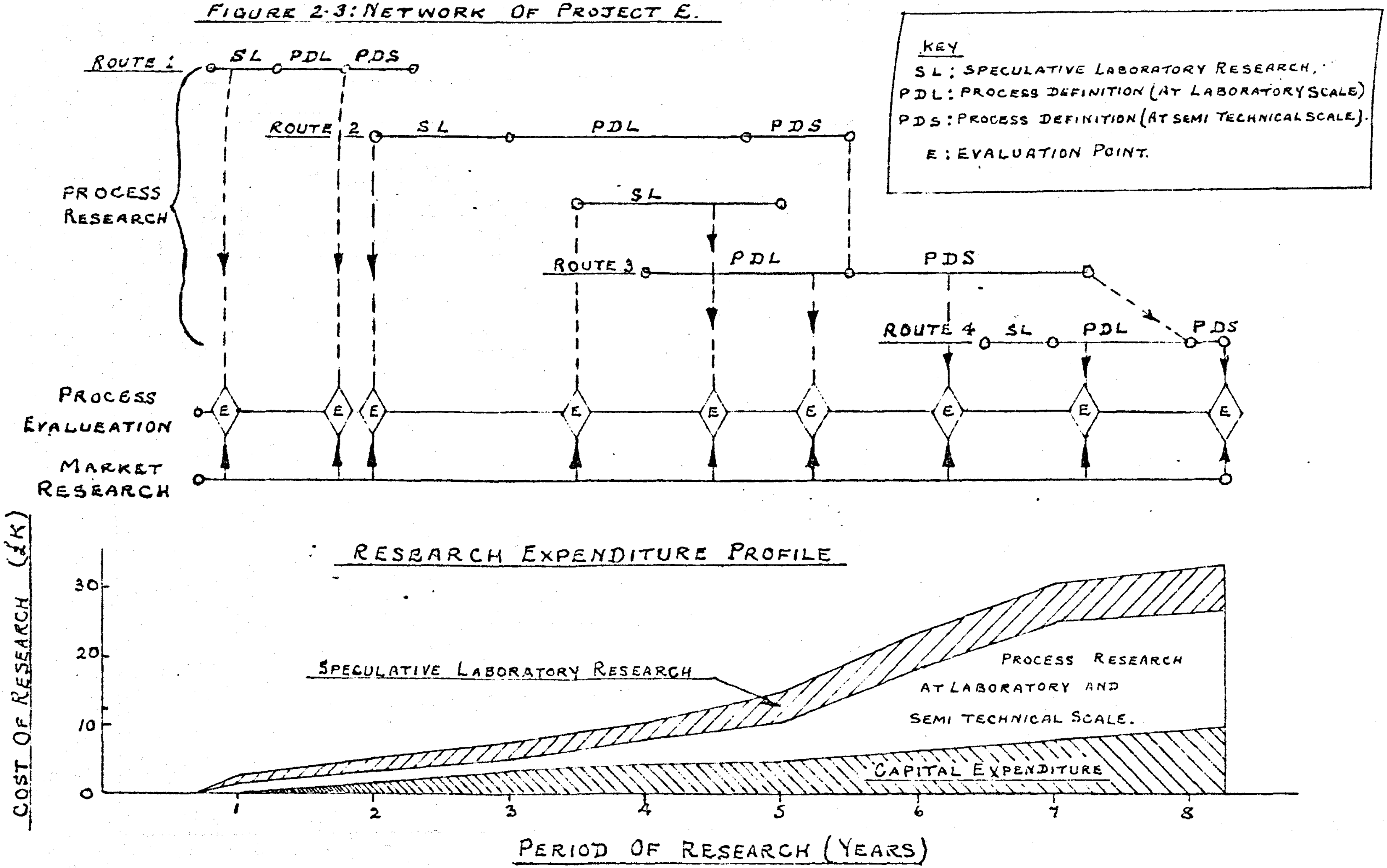


FIGURE 2·4: ESTIMATES OF THE MOND DIVISION DEMAND AND WORLD SUPPLY OF THE INTERMEDIATE.

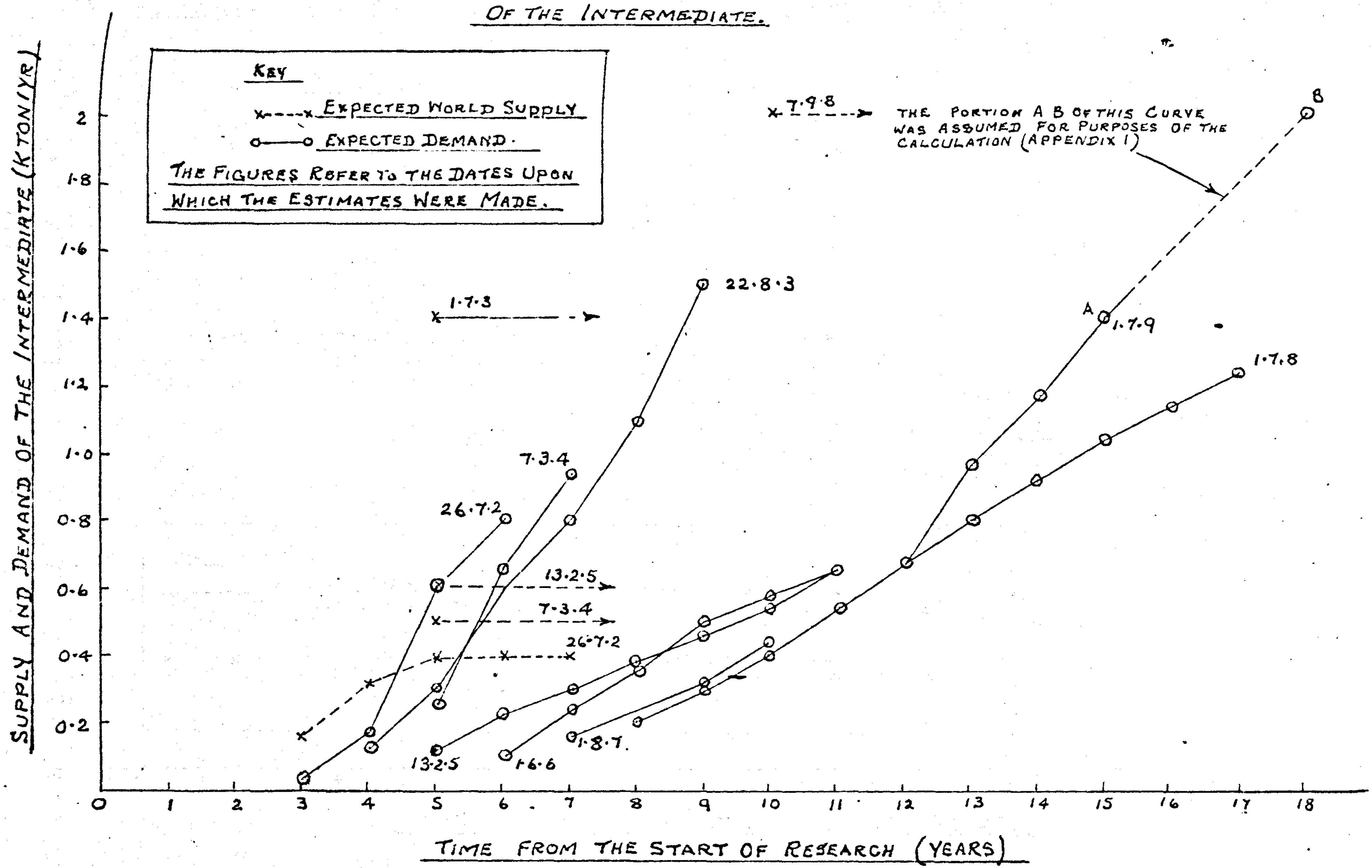
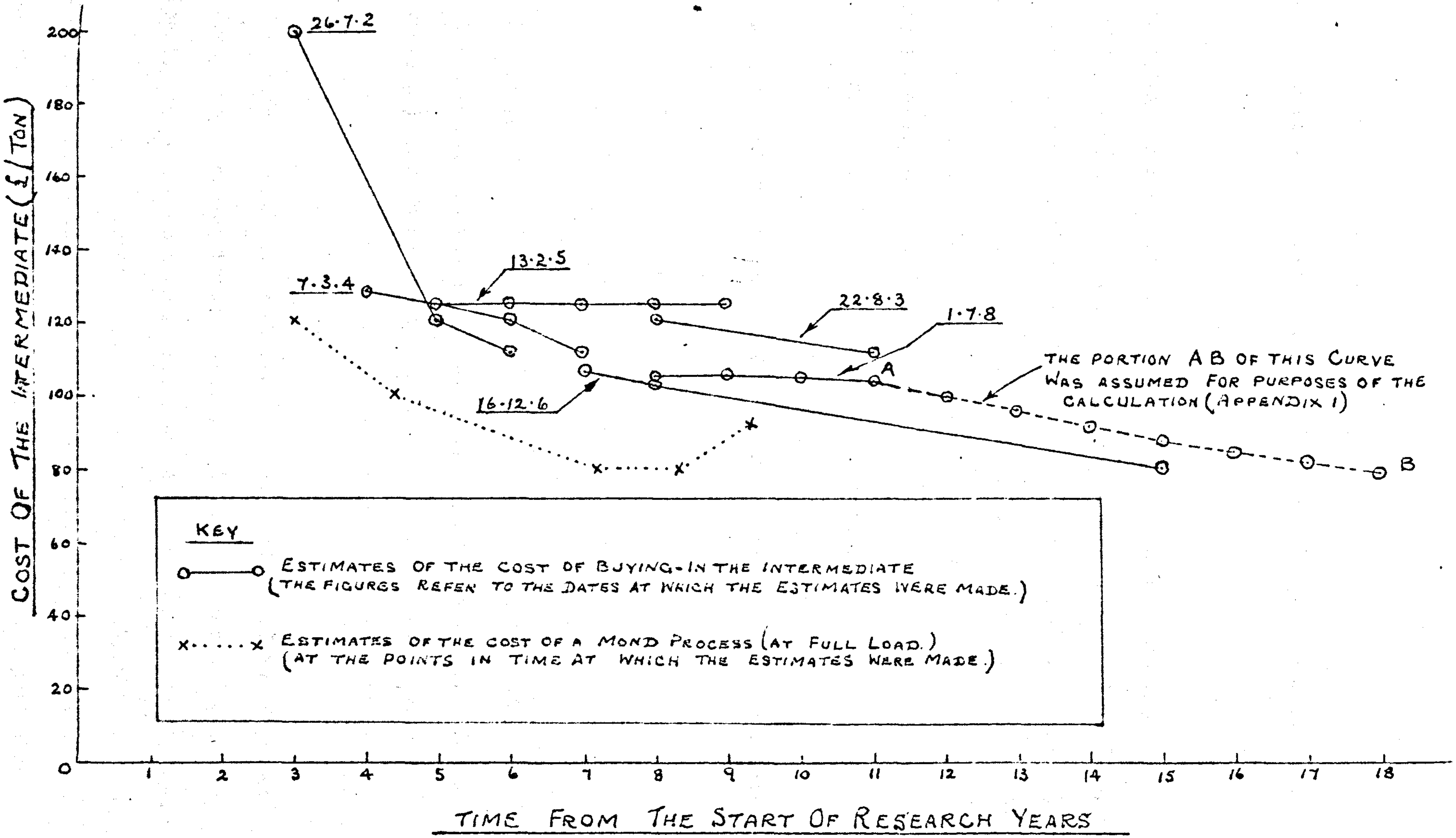


FIGURE 2·5: ESTIMATES OF THE COST OF THE INTERMEDIATE



on speculative research and process research, partly in the laboratory and partly at semi-technical scale. On the other hand process research predominated over the last three years of the programme.

A point which emerges strongly from Figure 2.3 is the cyclical nature of research; this was also emphasised by Bradbury et.al (58). The steps of: speculative work leading to process discovery, followed by process definition at laboratory, and at semi-technical scale, were repeated on four occasions. There were a number of reasons for the cyclical behaviour:

(1) Some of the routes ran into technical difficulties.

(2) The chance of demand exceeding supply was reduced as time progressed, as the growth of sales of the final product was less than originally estimated.

(3) The Division set more ambitious targets on production cost because of existing suppliers gradually cutting their prices.

The latter two points are illustrated by Figures 2.4 and 2.5, the data for which was obtained from the original project files. Figure 2.4 shows (a) that forecasts of demand for the intermediate were consistently high and had to be revised downwards at later times, and conversely (b) that forecasts of world supply increased as time passed. The forecasts made in year 2 (26.7.2) showed that demand was expected to exceed supply midway through year 4 - about 2 years ahead of the forecast. In year 8 however it was clear (from the estimates of supply 7.9.8 (2kton/yr) and demand 1.7.8) that supply would remain in excess of demand for many years. Figure 2.5 shows how forecasts of the cost of the intermediate on the open market decreased over the period of research, from ~ £200/ton 26.7.2 to ~ £105/ton 1.7.8, and also how the gap between this cost and the expected cost, using a Mond process, narrowed.

Figures 2.4 and 2.5 provide good examples of the degree of uncertainty which accompanies forecasts of both technical and market data.

At first sight, it might be considered that the project had been a failure. Eight years and approximately £33k, had been spent on research, but none of the processes developed looked sufficiently attractive to warrant the building of a full-scale plant. The situation that existed at the beginning of the research (of buying-in the intermediate, of licencing a process, or of developing a new process) therefore remained unresolved.

It may be argued however, that the research earned a modest return. The argument rests on the assumption that if Mond Division continued to buy-in, and if research had not been done, then the cost C of the intermediate over a period, would have been ΔC £/ton greater. The calculation supporting the argument are presented in Appendix 2, it is shown that if ΔC is assumed to equal 0.35C, then over a ten year period from the end of research (i.e. over years 9 to 18 inclusive) the savings, on the cost of the intermediate, just equal the research costs. Furthermore, if ΔC equals 0.15C, then over the same period the DCF rate of return of (Savings - Research expenditure) is $\sim$ 17%.

A further return on the research was the insurance cover provided. Although, in the event, demand for the intermediate remained within the supply limits, the existence of a worked-up internal manufacturing route was a valuable safeguard to the uninterrupted development of the business in the final product.

2.3 A critique of the use of existing systems of evaluation and control.

After examining a number of past projects, it was evident that from time to time many of the methods described in Chapter 1 had been applied within Mond Division. Examples are: checklists, scoring models, decision trees, risk analysis. It seemed likely however that these methods could be much more effective if linked in a co-ordinated and regularly applied system. A further useful development was thought to lie in an attempt to match projects, more explicitly than hitherto, to the divisional and company planning. These points, together with other problems of project evaluation and control, are now discussed in greater detail drawing attention to problem areas where possible from the REM's of project E.

2.3.1 Key aspects of Project Evaluation.

These may be summarized under two heads:

(1) The Statement of Assumptions.

Almost all the data used in the evaluation of the project return, and indeed the criterion used to measure the project return, require qualification. It is important therefore that the assumptions are presented clearly. The usefulness of an estimate of the capital cost of a plant is substantially reduced unless the site, the year of commission, the capacity of the plant etc., are made clear. Similarly if NPV is the criterion used to evaluate the return, then assumptions upon which the caluclation is based must be quoted: the rate of discount, the year from which discounting was started, the number of years in the calculation etc. It was found that a frequent practice was to compare processes on the basis of the cost of the product at full output of the plant. Sometimes the assumption of full output was lost in the various stages of information processing during the preparation of REM's (see Section 2.1.2). For example, with respect to project E, costs were usually compared at the full output of the projected plant (1000 ton/yr). In year 6 a plant, to be commissioned in year 8, was under discussion; it is evident from the forecasts of 1.6.6., 1.8.7. and 1.7.8. (Figure 2.4) however, that an output of 1000 ton/yr may not have been achieved until some years after the start-up of the plant, but this point was omitted from the relevant REM. The assumption of full-output working is acceptable, providing it is explicit in the document supporting further research, and providing the consequences of not reaching full output immediately are clearly spelt out.

(2) The treatment of uncertainty.
The need for an examination of uncertainty, and some of the methods of dealing with decisions subject to uncertainty, was made clear in Chapter 1 (Section 1.3.1). The extent of uncertainty in forecasts is well illustrated by Figures 2.4 and 2.5. It is clear that forecasts of the eventual project return should include an analysis of the implications of continuing the project in the event of other than the 'expected' situation occurring.

Although REM's are not the place for a detailed analysis of uncertainty, the case for further research on project E rarely referred to more than one estimate of the project return. For example in only two of the eight REM's were the implications of uncertainty developed. In the first the effect of different raw material prices on the cost of the intermediate was discussed, and in the second the consequences of different raw material conversion efficiencies was spelt out.

2.3.2 Critical factors in project control.

Project control is concerned with ensuring that the project is aimed at the goal, whilst resources are utilised in the most efficient manner. This requires regular monitoring of the benefits and costs of research. When results deviate significantly from plans, then tactics should be reconsidered. Some methods of project control reported in the literature are described in Section 1.5.

Good project control is dependent on:

(1) Suitable criteria being used to measure the costs and benefits.
(2) Consistent use of the criteria.
(3) Regular comparison of successive evaluations.
(4) Statement of interim objectives in each expenditure proposal.
(5) A total system scan.

The first two of these requirements are closely related to some of the points raised in the section above (on project evaluation). Past projects provided examples of the choice of a criterion which could prove to be misleading, and of criteria not used consistently at successive project evaluations.

The REM's of Project E provided examples of different criteria used to justify further research at successive evaluations. These included the cost advantage of a Mond process (at full-output) over alternative means of supply, in terms of on some occasions £/ton, and on other occasions £/yr. As suggested above, such criteria can be misleading if full output is not achieved soon after commissioning. The use of more than one criterion adds to the difficulty of comparing successive evaluations, furthermore neither of the criteria cited above permit a ready comparison of the benefit of a Mond Division process with the cost of research.

Though Project E was regularly assessed, there is evidence to suggest that successive evaluations of the cost advantage of a Mond process were not the most important basis of project control. The message of hindsight is that although the detailed cost and supply situation changed dramatically over the first four years of research, the security of supply objective remained dominant and decisive. (Figures 2.4 and 2.5 show that both the cost advantage of the Mond produced intermediate, and the chance of demand exceeding supply, declined as time progressed). It is for this reason that research strategy did not change significantly. It could be argued, however, after studying Figures 2.4 and 2.5 that in the later years of the project, the ratio of speculative to process research should have been changed in favour of more exploratory work, with the objective of increasing the long term options. This appeared preferable to further development of routes for the short term, which although well enough defined to provide the necessary security of supply, had no significant cost savings to offer. (The later Mond Division routes offered the intermediate at a cost only marginally below the going market rate.)

2.3.4 Relation of projects to company planning.

The fairly recent development of company planning , as an organised central activity of large firms, gives an important new dimension to project selection and evaluation procedures. Although strategy enunciation is in its early development, it is timely to attempt a matching of research projects with company objectives. Had this been functioning at the time of project E, a more explicit statement of project objectives would have emerged. The requirement for security of raw material supply would match well the company long term objective of 'flexibility', or the ability to react with appropriate speed to threats and opportunities. The objective of project E formulated in this way, as an insurance against loss of business by providing flexibility in dealing with possible raw material shortage, would have been influencial in shaping the project more effectively to this end. In its absence, the insurance provision was made, but perhaps more expensively and in a tactically less efficient manner than might have been the case.

2.4 The research programme.

The foregoing analysis of key aspects of project evaluation and control, with the help of the historical model provided by past research projects, showed that some useful advances might result from an organised system of project evaluation and control. This path was preferred to any attempt to add yet another technique to the existing selection. It was also preferred to work on the 'portfolio approach' to project selection, for the reasons given in Section 1.4.2.

It is expected that the system of project evaluation and control created, will be of some general interest and application. The literature is predominantly concerned with techniques of project evaluation, project selection, sensitivity analysis, risk analysis etc., with relatively little attention to the need for linking up these techniques into unified systems.

The system developed may claim these attributes:

(1) It attempts to recognize and assess all factors relevant to project evaluation.

(2) It quantifies these factors in money terms where appropriate and by scores where appropriate.

(3) The design is conducive to the detection of changes in the project status and is flexible in its applicability.

(4) The system does not attempt to eliminate judgment but to inform it.

(5) In so far as it secures a regular and comprehensive overview of the emerging project it provides the total system scan so insuring against serious omissions in project development.

Chapter 3

A NEW SYSTEM OF PROJECT EVALUATION AND CONTROL.

This Chapter is concerned with the development of a formal system of project evaluation and control. The objective was a system that would enable better decisions to be taken and a finer degree of project control to be exercised. Whilst the system is based largely on techniques described in Chapter 1, it is considered that it is novel in application and constitutes a practical procedure that avoids some of the weaknesses inherent in these techniques and some of the problems raised in Chapter 2. The results of applying the system are discussed separately in Chapters 4 and 5. Chapter 4 concentrates on the more immediate short term or tactical problems, whereas Chapter 5 is concerned with the wider, longer term, issues that are involved.

The work of H.A. Simon (59), provided a convenient model of the process of managerial decision and control. Simon made a study of the approach to decision and moved away from the concept of a 'point' of decision, towards a 'process' of decision. This was divided into three steps:

(1) Intelligence: searching the environment for conditions requiring a decision, i.e. problems.

(2) Design: inventing, developing and analysing, possible courses of action.

(3) Choice: selecting a particular course of action from those available.

Simon's work has been elaborated by several authors.

Clarke (60) and Soelberg (61) have both extended the model to include the steps 'implementation' and 'control'. Morris (40) has added to this the step 'learning' recognising that the results of the decision will be compared with aspirations, and that experience will be gained.

For the purposes of the author's work, the 'control' step of the cycle was assumed to be concerned with monitoring progress. When a significant deviation between achievement and plan was evident, then a return to the 'intelligence' or 'problem identification' step was assumed to have occurred. The process of decision and control may therefore be conveniently represented by the cycle shown in Figure 3.1. (Clarke, Soelberg, and Morris also draw attention to this point.)

The feedback link from 'control' to 'problem identification' is important. This might seem abundantly clear to those concerned with the control of mechanical systems, such as manufacturing processes or space craft. Nevertheless, a surprising number of apparently successful research projects have failed at an advanced stage because insufficient attention has been given to reviewing the assumptions upon which success depends, and to comparing achievements with plans. A good example of this, though slightly out of the research context, is to be found in a report issued by A.D. Little Inc (62), who had been commissioned to review and criticise transportation planning for the city of Washington D.C. It was found that all the plans formulated over the period 1955 to 1965 depended on survey data collected in 1955; during the time period however, travel behaviour changed significantly*.

* The author is indebted to Mr.B.J. Loasby of the Department of Economics, University of Stirling, for citing the 'Transportation Planning' example and for his help in the preparation of the opening section to Chapter 3.

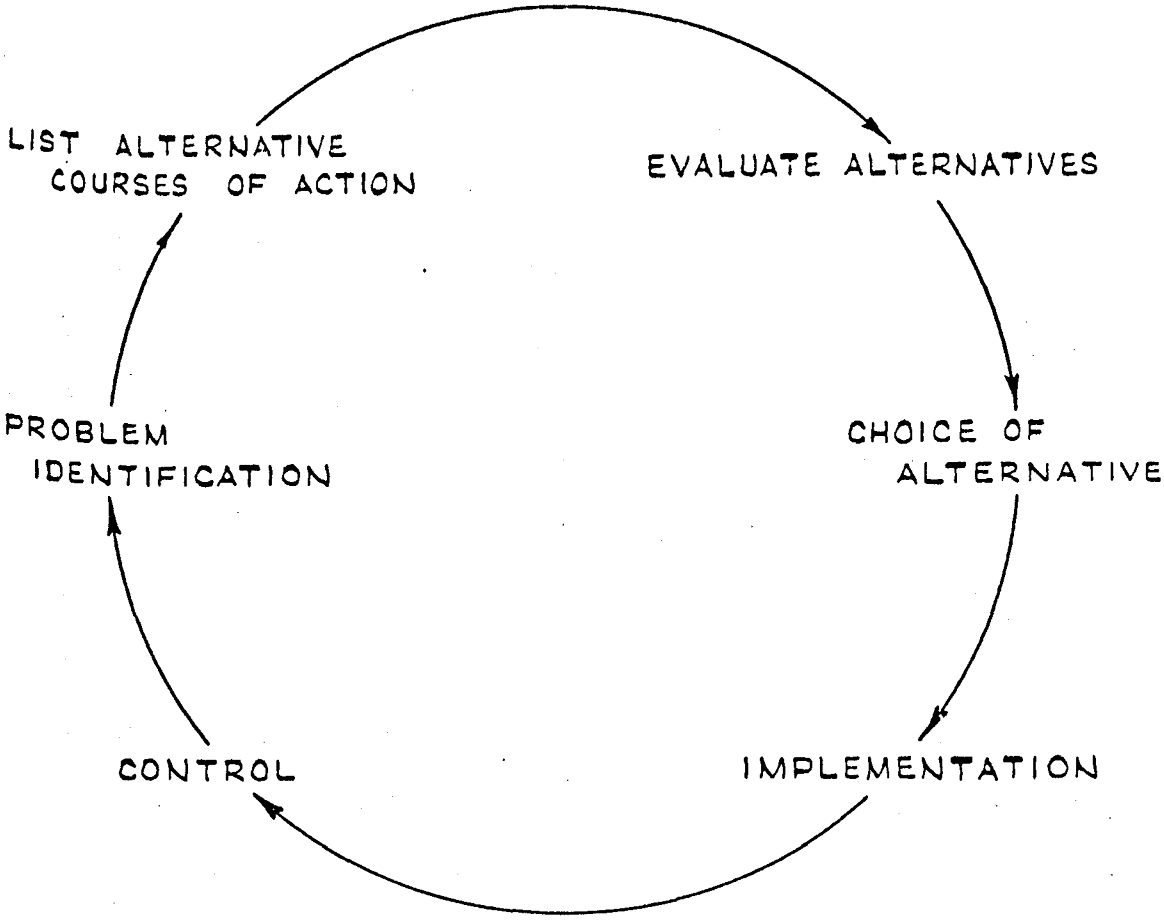


FIGURE 3.1 THE CYCLE OF DECISION AND CONTROL

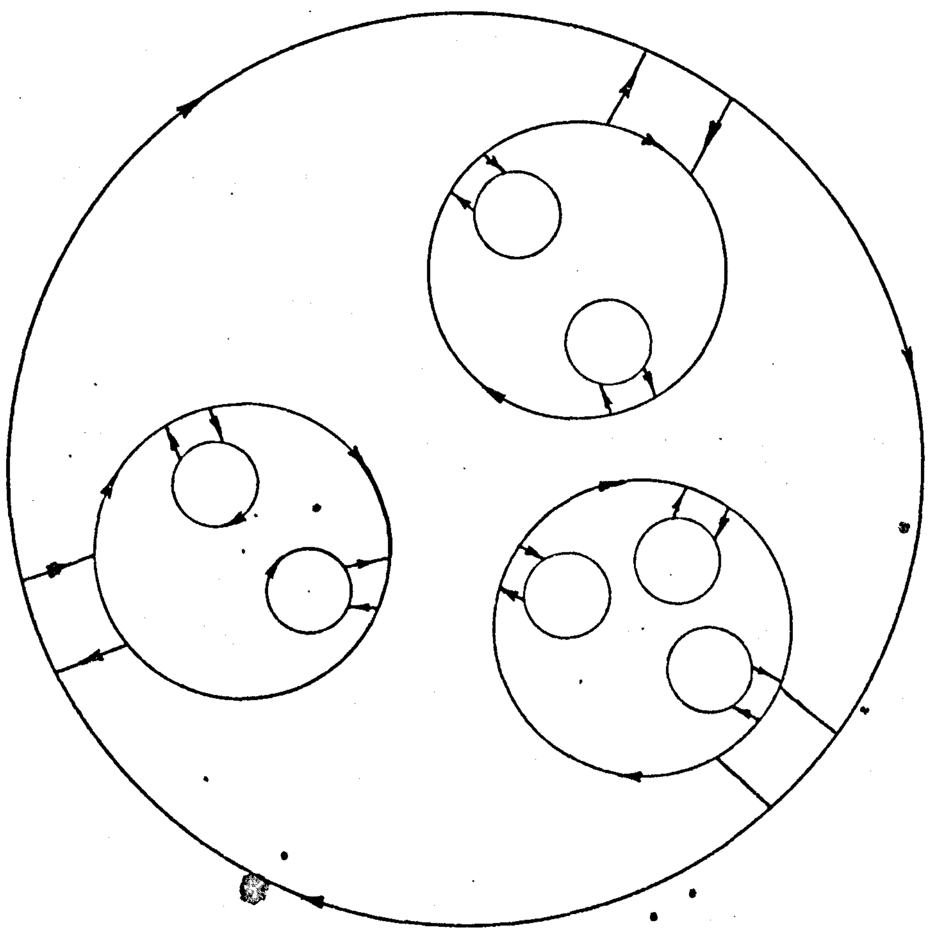


FIGURE 3.2 THE HIERARCHY OF CYCLES OF DECISION AND CONTROL

3.1 The Objectives and Structure of the New System.

Within a large organisation there is usually a hierarchy of cycles of decision and control, corresponding to different management levels. This is shown diagramatically in Figure 3.2.

At the highest level, represented by the outermost cycle, is the Company Chairman, and at the lowest, represented by the innermost cycle, is the junior assistant. The interconnections between the cycles are an important aspect of the system, these represent the flows of information up and down the hierarchy. The flows down the hierarchy define the work to be undertaken and place constraints on the area in which the work is to be done. The flows up the hierarchy are concerned with the achievements of past work and suggestions for the future; they may also have the effect of modifying the constraints, company planning in the chemical industry being sensitive to leads from R & D.

It is interesting to note the phase differences between the cycles of the hierarchy. The choice step of the Chairman's cycle could be a signal for 'implement' in the next lower level of management's cycle. Similarly, the 'control' step of the laboratory assistant performing some experiments could be a signal for 'problem identification' in his immediate superior's cycle.

The system for project evaluation and control, developed during the course of the author's research was designed to operate at the project management level and was based on the cycle shown in Figure 3.1. The objective stated in the opening to this Chapter was to be achieved by providing management with an improved base of information related to the prospects and progress of research. The steps of the cycle concerned with 'listing the alternative courses of action', 'evaluation' and 'control' received particular attention. The following sections of this Chapter discuss the approach taken to each of these steps. It was assumed that the steps of 'choice', 'implementation', and 'problem identification' depended largely on the judgment of the project management team.

3.2 Listing the Alternative Courses of Action.

When, in the terms of the cycle, a 'problem situation' has been identified, the alternative courses of action might be clear. If the Marketing Department reports that sales of product P will outstrip capacity in five years time, the alternatives might be restricted to:

(1) Extend the existing plant.

(2) Build a new plant employing (a) a competitor's process, or (b) a new process developed in the research department.

(This list could be extended perhaps, by including some different building schedules).

On the other hand, if the research was in support of a plant which failed to operate according to specification, it might be necessary to employ a technique for generating alternatives more systematically. Such a technique is 'Critical Examination' which was originally developed by ICI. The procedure is to allow a small group of informed persons to analyse a problem, or desired achievement, and to generate alternative approaches. The method uses a framework based on some key words: what, where, how, who, etc., and is described by Raybould (63) and Baines, Bradbury and Suckling ((5) page 216). A worked example of the use of critical examination in process design is provided in a paper by Elliot and Owen (64). A conventional decision tree network (Section 1.3.1) was chosen as the means of presenting the various alternative decisions. This method has the useful properties of displaying each future activity, of connecting them in a logical manner and of highlighting future decision points. A time scale too may be included.

3.3 The Evaluation of Alternative Courses of Action.

Evaluation was taken in two stages, the first was the completion of a checklist for project viability. This was largely qualitative and had the virtue of being applicable at all phases in the life of a project. The second stage was a financial evaluation, in which a monetary value was placed on the results of exploiting the research. As time progresses and quantitative information concerning costs of production and markets becomes more realistic, the financial part of the evaluation assumes greater importance.

3.3.1 The Checklist for Project Viability.

This checklist was designed to give the project team a shorthand picture of the complete emerging system, to help them to form a balanced view of the future prospects of the project and to allocate resources to the next phase of research. A particular aim was to reduce the likelihood of situations arising in which one aspect of the project receives excessive attention to the detriment of other aspects which may be equally or more important. It is all too easy to devote effort to minor improvements to the emerging project whilst overlooking some factors which may be of vital significance; an effluent problem or discoloured product might be in the latter category for example.

The checklist was designated a viability checklist because such points were included in its scan.

Some of the checklists which have been proposed in the literature are discussed in Section 1.2. The checklists used in the author's research were drawn up after a series of trials on current projects in Mond Division, Research & Development Department. The sets of factors were collected under three main headings: raw materials, process, and product and market.

Raw materials were considered by drawing attention to security of supply, price trends, quality and hazards. The process was scanned by considering the major plant items such as reaction stage or purification stage, as possible problem centres. The well known problems of process development, such as corrosion,process control and effluent treatment, were also listed. The product and market were assessed by reference to (a) the properties of the product: its uniqueness, quality and cost effectiveness; (b) problems of market preparation such as large scale testing of the product and authorisation for use; (c) questions of product acceptance by the user, which included customer identification, compatability with customer's equipment and product obsolescence rate.

The checklist respondents were invited to assess each factor on the scale: no problem, minor problem, major problem, major threat, ignorance. It was also required that each entry be qualified by appropriate comment in an adjacent space provided on the forms.

No precise rules were laid down for rating factors but the following were used as guidelines:-

No problem

The factor requires no further research and imposes no threat.

Minor Problem

The level of performance expected of the factor is in some doubt, but the adverse effect on the eventual project return is unlikely to be great. Alternatively a factor which is substantially off target, but which is likely to be brought on target by a minor effort would also be classed as a minor problem.

Major Problem

The level of performance expected of the factor is not yet achieved. The adverse effect on the eventual project return of continued non-achievement could be great. Further research may solve the problem, but the amount of effort required may be substantial.

Major Threat

As for major problem, but indicating situations where solutions are not forthcoming, and where available research effort is not expected to reduce the threat significantly.

Ignorance

There is insufficient information available to assess the likely performance. A viability checklist, in completed form, is presented in Figures 4.2 and 4.3.

3.3.2 The Financial Evaluation.

As financial evaluations of research projects must be made under conditions of uncertainty, it was decided to employ the risk analysis technique (Section 1.3.1) to provide an indication of the uncertainty associated with each alternative course of action. The other methods of either allowing for (or measuring) uncertainty, discussed in Chapter 1, were not considered to be acceptable for the reasons given there.

The criterion evaluated using the risk analysis was net present value (see Appendix 1), though as will be seen in Chapter 4, the values of some other criteria are also estimated. For each variable used in calculating NPV the following information was required:

(1) An estimate of the mode (i.e. the most likely value).

(2) An estimate of the range within which values of the variable will lie.

For convenience this was chosen to be a 95% confidence interval because of its simple connection with the standard deviation of the normal distribution. (The 95% confidence limits of a normally distributed random variable are located 1.96 (say two) standard deviations away from the mean.) It was, of course, quite acceptable, if it was preferred, for estimates to be given in terms of other convenient confidence intervals such as 80% or 90%. The data are recorded on a series of forms, which also require a statement of the assumptions upon which the data are based. Experience gained collecting data is discussed in Section 4.7. A completed set of forms are presented in Figures 4.5 and 4.6 to exemplify the procedure. The computer programme used to perform the risk analysis calculation is discussed in Section 3.5.

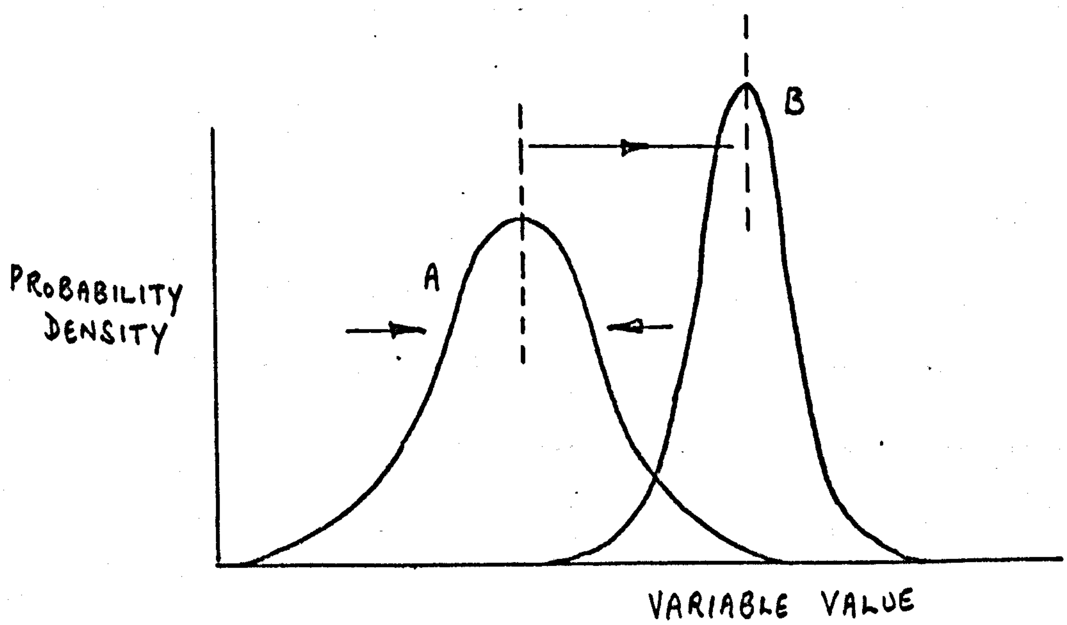
As research is a dynamic situation in which estimates of variables are continually changing with time, it was found useful to define data, and to evaluate the project return, in two distinct situations: the 'as of now' situation and the 'after research' situation. The former estimates were based on information already available from the literature, from past experience, or from previous process or market research; the latter were based on estimates of what might reasonably be expected to emerge in the future, as a result of research and development at the present or some other defined level. Two of the most important functions of R & D in industry are:

(1) To change the values of variables such that the eventual return of the project is enhanced.

(2) To reduce the uncertainty surrounding the values of the variables.

The diagram below shows how the 'as of now' and 'after research' situations may be used to illustrate these functions.

Figure 3.3



Distribution A expresses the estimate of the variable in the 'as of now' situation. One possible effect of research expenditure is shown by the arrows. Distribution A is transformed into distribution B, which has a smaller spread and larger mean. (Or, in the case of cost variables, smaller mean).

For example, in the situation immediately following some laboratory research, the mode and 95% confidence limits on the raw material cost might be estimated to be £300/ton $\pm$20% in the 'as of now' situation. But the project chemists might be aware of several areas where research could lead to improved reaction yields, and similarly they might believe that semi-technical scale working would reduce the uncertainty. The raw materials cost in the 'after research' situation might therefore be estimated to be £250/ton $\pm$10%.

On the other hand, each of the areas might prove to be sterile, and reveal not an improved cost but an unforeseen increase in cost. At the same time, however, it is likely that the uncertainty will be reduced. Thus in the example above, the raw materials cost after research might later be estimated to be £320/ton $\pm$10%.

The final step in the financial evaluation was a sensitivity analysis. This is a technique well known in economics, which can be helpful in resource allocation, as the analysis highlights areas where resources may be applied most effectively. Suppose $y = f(x_1, x_2, x_3, \ldots . x_n)$, then the sensitivity of y to changes in x_i is defined by:

$$\Delta y = f(x_1, x_2, \ldots x_i, \ldots x_n) - f(x_1, x_2, \ldots x_i', \ldots x_n),$$

where x_i' is a new value of variable i close to x_i.

As the project return was expressed in terms of a probability distribution, the sensitivity of the mean of the distribution (the project return R) and the standard deviation of the distribution (the project uncertainty U) were each examined:

(1) The sensitivity of the project return to changes in variable i, was found by changing the value of variable i by 10% and determining the change in project return R. In cases where variables were expressed in terms of a mode value and a 95% confidence interval, each of the three estimates was changed by 10%.

(2) The sensitivity of the project uncertainty to changes in the uncertainty surrounding variable i was found by holding the value of this variable at its mode value (i.e. taking out the uncertainty surrounding variable i), and repeating the determination of the distribution of project return. The change in U then provided an indication of the contribution of variable i to the overall uncertainty of project return.

In all the sensitivity tests the variables in the financial criterion, other than i, retained their original range of values (as defined by the mode and 95% confidence interval), and the risk analysis programme was used to determine the new values of R and U. This procedure was repeated for each variable in turn. Some methods of generalising the results of both sensitivity analyses are presented in Appendix 4.

A sensitivity analysis may be performed in a variety of different ways. For example, Baines, Bradbury and Suckling ((5), page 64) tested the sensitivity of return by changing the mode value of each variable in turn and recording the effect on the mode value of the criterion selected (in this case payback period). No risk analysis was incorporated in these sensitivity tests. Moreover the change in the value used for sensitivity testing may differ from variable to variable.

In the case cited above for example, the sensitivity of payback period was examined with respect to a 25% change in capital cost and a 50% change in raw materials yield.

A description of the output of the financial evaluation is postponed until Chapter 4. It is sufficient to state at this stage that the results of the risk and sensitivity analyses are presented in both graphical and tabular form. As indicated in Section 3.1, it was not considered that the system's function was to determine the 'best' course of action and thereby indicate the choice to be taken. Choice must rest with the project management, who would use the checklists and financial evaluations to inform their judgment.

3.4 Project control and problem identification.

It was stated at the beginning of this Chapter that the 'control' step of the decision cycle (Figure 3.1) was assumed to be concerned with monitoring the progress of research. This involves regular evaluation of the project, and secondly the presentation of the results in a manner that facilitates comparison of successive evaluations and the comparison of achievements with plan. No specific time intervals between evaluations were defined, but projects were assessed at intervals of approximately three months. Both the checklists and the financial evaluation provided ready means of monitoring progress:

(1) Monitoring the checklist entries.

Figure 3.4

Checklist Factors	No Problem	Minor Problem	Major Problem	Major Threat	Ignorance
(i)	3		2		1
(ii)				1,2,3	
(iii)		3	2	1	
(iv)		3	1	2	
(v)	2,3				1
(vi)		1,2		3	

where 1 indicates the first assessment,

2 indicates the second assessment,

3 indicates the third assessment.

As illustrated in Figure 3.4, the procedure was to use integers to monitor profiles of the checklist entries at successive points in time. This enables those concerned to assimilate the general progress of work rapidly, as success is accompanied by a movement of entries from right to left. Some of the factors will be controllable, in the sense that they are susceptable to change by research on the part of the organisation running the project or by other means. Examples could be the improvement of reaction yields or of product quality. Other of the factors are uncontrollable and are dependent largely on the actions of others including competitors or Government. Examples would be the introduction of a superior product, or the imposition of tighter effluent legislation.

(2) Monitoring the financial evaluation.

Figure 3.5

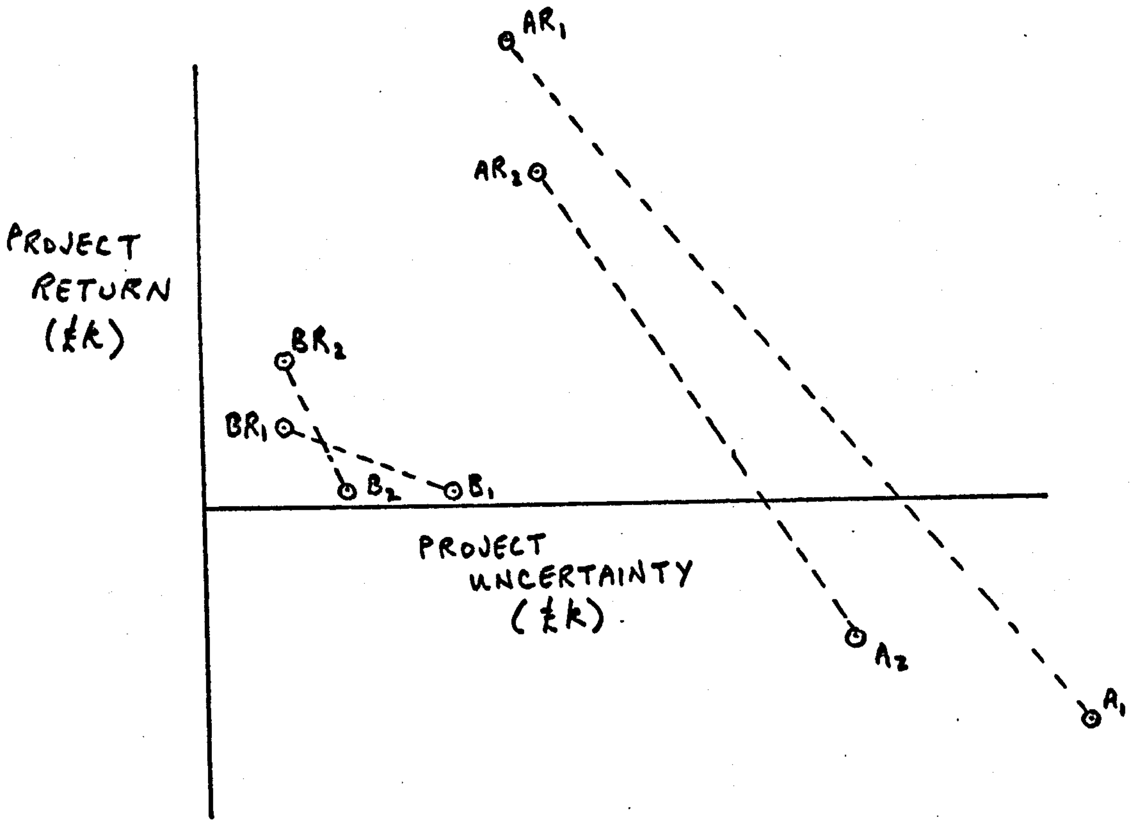


Figure 3.5 shows how the estimated return and uncertainty of the project were plotted at successive points in time. The points A_i and AR_i refer to estimates at time i in the 'as of now' and 'after research' situations. The points B_i and BR_i specify the corresponding values for the next best alternative course of action. If this alternative is to stop research, then the points B_i and BR_i would lie at the origin of the return - uncertainty axes. On the other hand, if the project was concerned with the definition of a new route to an existing product, the next best alternative could be a development of the existing process. The points B_i and BR_i could then define the implications of installing a plant based on existing technology and a plant based on an improved version of existing technology.

Signals highlighting problems are provided by both forms of monitoring. For example, the checklist indicates a lack of progress, or a deterioration of the project when, over a period of time, (a) entries in the 'major problem','major threat', or 'ignorance' column fail to move to the left, and (b) entries initially in the 'no problem' or 'minor problem' columns move to the right. In Figure 3.4, for example, problems could be identified by factor (ii) remaining a 'major threat' after two periods of work, or by factor (vi) reverting from a 'minor problem' to a 'major threat'. Similarly success should be accompanied, in the financial evaluation, by a movement away from the 'as of now' situation towards the 'after research' situation. Problems are identified, if successive evaluations fail to exhibit such a movement, or if the difference between the prospects of the project and those of the next best alternative is progressively reduced. For example, referring to Figure 3.5, problems could be identified at time 2 by (a) the very small increase in the expected return of the project, in the 'as of now' situation (compare A_1, A_2), (b) the less optimistic forecasts of the return of the project in the 'after research' situation (compare AR_1, AR_2), and (c) the reduction in the advantage of the project over the next best alternative (compare the difference between AR_1 and BR_1 with that between AR_2 and BR_2).

Once again, as for the question of choice raised in the previous section, the system goes no further than providing the management team with information. On this occasion the checklist and financial evaluation simply monitor the state or prospects of the project over time but they do so in a clear and realistic manner. The final step of the cycle of decision and control - 'problem identification' was assumed to have been reached when the management team decide that the changes evident are too large to be accommodated within the existing plan of the project. In this event, the various alternative courses of action would be drawn up and the future research programme would be decided after evaluation.

3.5 The risk analysis programme.

Some of the principles of risk analysis were outlined in Section 1.3.1. Although a number of risk analysis programmes have been written within ICI, and many of the computer manufacturers offer such programmes as part of their software packages, it was found desirable to write a new programme for the purposes of the author's research. The new programme offered several advantages especially in R & D:

(1) The assumptions built in to the programme were exactly those required by the user.

(2) The programme could be readily modified in response to requirements for changes to input, output, or logic.

(3) The programme was kept simple; complex programmes are not usually warranted in research, where the precision of data is often low.

(4) The programme was written to run on a local IBM 1130 computer. Restrictions were imposed on programme size and speed of execution, but these were considered to be more than balanced by the ease of access, and fast turn round of jobs. (About 6 K words of core storage were available for both programme and working area, - much less than is normally required by risk analysis programmes.)

A flow diagram of the computer programme is presented in Figure 3.7. The first part of the input data defines the scope of the calculation: the number of years N in the cash flow, the number of plants

NP (and for each plant the capacity C and the period required to build P), the number of markets NM, the number of simulations required n, the number of intervals in the histograms of project return NI which are output, and the discount rate r to be used. This data is followed by estimates of the mode M and the upper and lower limits U and L of a 95% confidence interval, for each variable subject to uncertainty:

(1) The capital, variable operating and fixed operating costs, associated with each plant.

(2) The annual demand and selling price, of the product, in each market.

There is also provision for including: 'other variable' and 'other fixed' incomes or expenditures, on a plant or annual basis. For example, selling expenses, research costs.

The working capital is defined by inputting a series of coefficients related to: stocks of raw materials, stocks of product, credit given by raw material suppliers, and credit given to customers, etc.

The main part of the programme repeats a calculation of NPV a large number of times. Each calculation is called a simulation and may be divided into two main parts:

(1) The selection of a random value of each variable subject to uncertainty.

In the case where M is placed symmetrically between L and U, it is assumed that the uncertainty in the variable may be represented by a normal distribution fitted through the limits of the confidence interval. Random values of variables are sampled by first calling a random number generator. (A library subroutine, which provides a stream of normally distributed random numbers R_i of zero mean and unit standard deviation.) A normally distributed random value of the variable V is then given by:

$$V_i = M + R_i \, (U-L)/3.92 \, .$$

Note: $(U-L)/3.92$ is the standard deviation of the normal distribution representing the uncertainty in V.

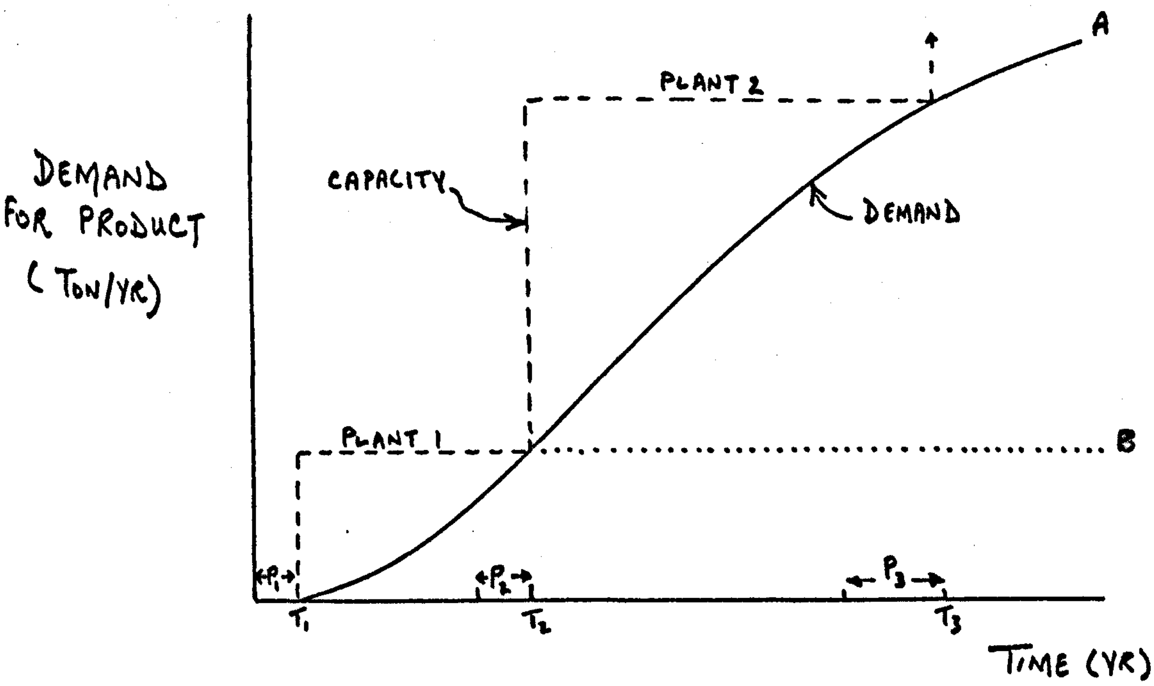
If the mode M is not placed symmetrically between the limits of the confidence interval, then uncertainty in the variable may be represented by a skew distribution. Examples are the triangular distribution suggested by Sprow (65), and the log normal distribution described by Aitchison and Brown (66). Both methods were considered and the former was written into the programme as an option, but the facility was never invoked. In the projects assessed by the author, it was felt that the quality of the information available did not justify the preference of a skew distribution over the normal distribution. For reasons of simplicity the latter was therefore used to represent the uncertainty surrounding all of the variables in the risk analysis calculations. The data input of the programme was therefore constrained so that the mode was always midway between the limits of the 95% confidence interval. A useful side-effect of this approach was that more space was available in the computer, as only two points were required for each item of data subject to uncertainty.

(2) The calculation of net present value.

When each of the distributions defining the uncertainty in variables have been sampled, the programme goes on to determine the net present value (NPV) of the simulation.

The first step is to determine the profile of capital expenditure over time. The logic of the computer programme is presented in the flow diagram Figure 3.7, and is explained with reference to Figure 3.6.

Figure 3.6



First the programme makes a check of demand against the capacity of the first plant. If this capacity is not exceeded over the period of operation of the plant, capital to cover the first plant is spent over the period P_1 in the manner defined in the input data. If the capacity of the first plant is exceeded, then either demand is reduced to match the capacity of the first plant (as in profile B), or if a second plant is specified capacity is increased and further capital spent. In the latter case T_2, the point at which demand exceeds capacity, is determined and capital is spent on the second plant during the period P_2. If necessary third and fourth plants may be introduced in this manner, thus enabling the demand curve defined by

A to be satisfied.

The remainder of this part of the programme calculates the NPV of the simulation in the usual manner. The formula is given in Appendix 1. In each of the samples considered a discount rate of 15% was used and NPV was determined before tax and investment grants. The output of a typical computer run is presented in Figure 3.8. For each year of the calculation, a histogram is printed which indicates the number of simulations falling within equal divisions of the range of NPV. The user is free to set the number of intervals in the histogram, and as illustrated in Figure 3.8, the programme prints the end points of the intervals, the mid-points of the intervals, the frequencies, and the mean and standard deviation of the set of simulations. If it is necessary the programme goes on to perform a sensitivity analysis, all that is required are cards defining the new values of the variables under examination. The time taken by the computer to execute the risk analysis programme depends on the complexity of the calculation: the number of plants, the number of markets, the number of years, to be considered. In the runs performed by the author, the time per simulation was between 2 secs., and $3\frac{1}{2}$ secs., with a fixed time of about 2 mins., per run for the steps of programme compilation, set-up of the machine, and output of results. The time for a 100 simulation run might therefore be expected to lie between 5 and 9 minutes. At rates of about 3 shillings/min (the approximate cost of the 1130 computer including overheads), the cost of a risk analysis run could therefore amount to between 15 and 27 shillings.

Some tests on the programme are described in Appendix 3.

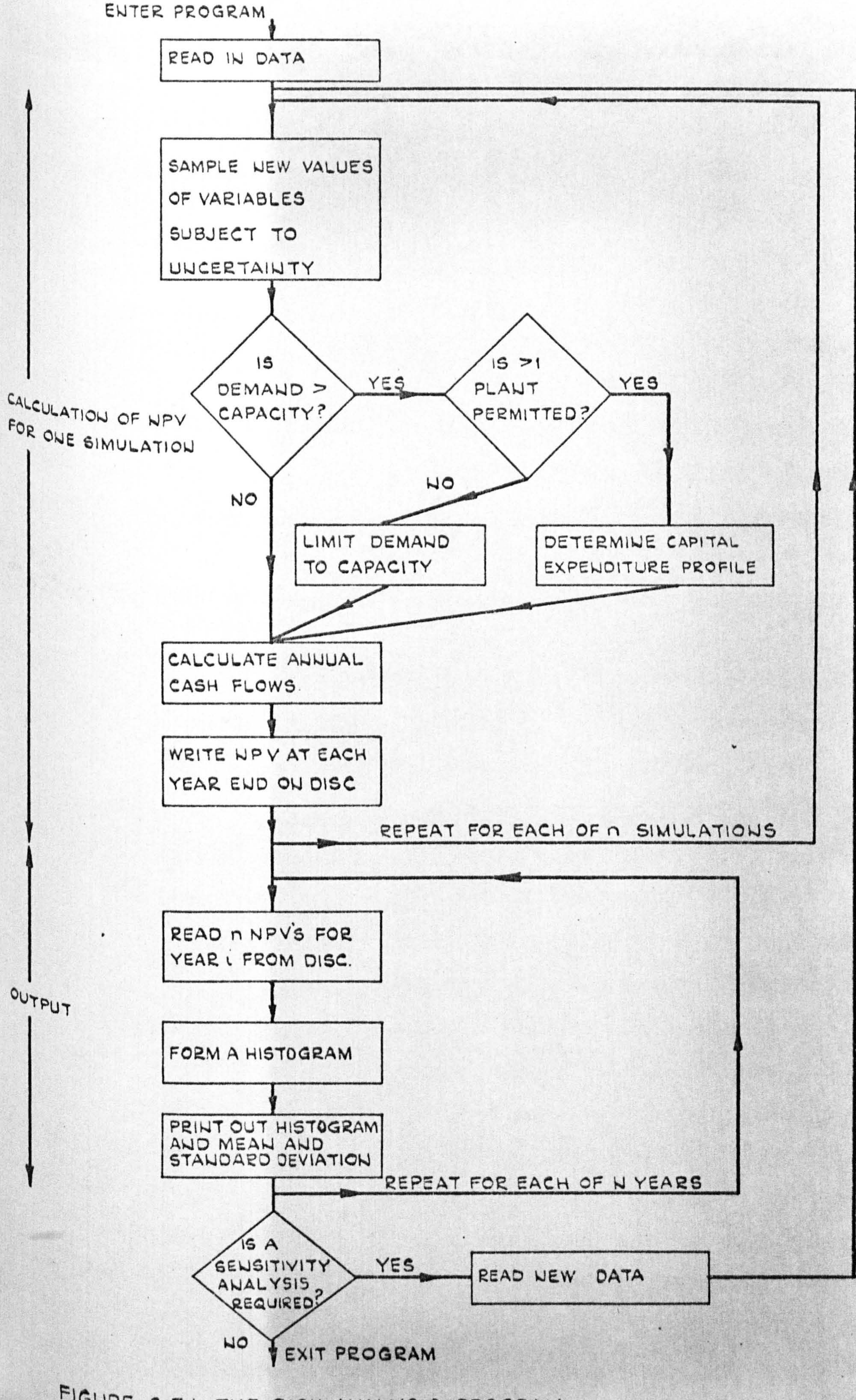


FIGURE 3.7: THE RISK ANALYSIS PROGRAM.

FIGURE 3.8

OUTPUT-NET PRESENT VALUE HISTOGRAM FOR EACH YEAR

HISTOGRAM YEAR 1

INTERVAL END PTS	-986.7	-951.5	-916.4	-881.2	-846.0	-810.8	-775.6	-740.5	-705.3	-670.1
INTERVAL MID PTS		-969.1	-933.9	-898.8	-863.6	-828.4	-793.2	-758.1	-722.9	-687.7
FREQUENCIES		3	11	10	19	21	18	9	6	3

MEAN = -833.9 STANDARD DEVIATION= 68.3

HISTOGRAM YEAR 2

INTERVAL END PTS	-1896.2	-1828.6	-1761.0	-1693.4	-1625.8	-1558.2	-1490.6	-1423.0	-1355.4	-1287.8
INTERVAL MID PTS		-1862.4	-1794.8	-1727.2	-1659.6	-1592.0	-1524.4	-1456.8	-1389.2	-1321.6
FREQUENCIES		3	11	10	19	21	18	9	6	3

MEAN = -1602.6 STANDARD DEVIATION= 131.3

HISTOGRAM YEAR 3

INTERVAL END PTS	-1844.0	-1767.7	-1691.4	-1615.0	-1538.7	-1462.3	-1386.0	-1309.7	-1233.3	-1157.0
INTERVAL MID PTS		-1805.9	-1729.5	-1653.2	-1576.9	-1500.5	-1424.2	-1347.8	-1271.5	-1195.2
FREQUENCIES		2	11	9	18	23	19	7	8	3

MEAN = -1505.6 STANDARD DEVIATION= 147.0

HISTOGRAM YEAR 4

INTERVAL END PTS	-1617.9	-1532.2	-1446.6	-1361.0	-1275.4	-1189.8	-1104.2	-1018.6	-933.0	-847.4
INTERVAL MID PTS		-1575.0	-1489.4	-1403.8	-1318.2	-1232.6	-1147.0	-1061.4	-975.8	-890.2
FREQUENCIES		2	10	9	18	22	19	8	9	3

MEAN = -1235.8 STANDARD DEVIATION= 162.0

HISTOGRAM YEAR 5

INTERVAL END PTS	-1304.7	-1210.2	-1115.6	-1021.1	-926.5	-832.0	-737.4	-642.9	-548.3	-453.8
INTERVAL MID PTS		-1257.4	-1162.9	-1068.3	-973.8	-879.2	-784.7	-690.1	-595.6	-501.0
FREQUENCIES		3	9	9	15	26	18	9	7	4

MEAN = -880.2 STANDARD DEVIATION= 177.0

HISTOGRAM YEAR 6

INTERVAL END PTS	-363.0	-282.6	-202.3	-122.0	-41.6	38.6	118.9	199.2	279.6	359.9
INTERVAL MID PTS		-322.8	-242.5	-162.1	-81.8	-1.5	78.7	159.1	239.4	319.7
FREQUENCIES		2	8	10	17	24	16	11	8	4

MEAN = 1.6 STANDARD DEVIATION= 149.4

Chapter 4.

SOME PRACTICAL TESTS OF THE SYSTEM.

The system for project evaluation and control described in Chapter 3 was tested on a number of research projects. This chapter presents some results and discusses experience of application. Two projects are described in detail, these are labelled M and N. Project M is used to illustrate the steps of the cycle (Figure 3.1), concerned with the presentation of the alternative decisions, evaluation and choice. The approach to the control step is illustrated with reference to project N.

4.1 Project M.

This project was concerned with the development of a process to a new product that was to be marketed by another Division of ICI. Research work had been in progress for about two years during which time three routes to the product had been discovered (R_1, R_2, R_3). Route R_2 was the best established and had already been used to produce small quantities of the product. Work on routes R_1 and R_3 was started at a time when prospects for R_2, as a process for large-scale manufacture, were not considered to be very promising. Route R_3 appeared to be a great success at laboratory scale but later had to be ruled out on grounds of a possible effluent problem. Process R_1 involved slightly more sophisticated chemistry than route R_2 and comprised an extra process stage.

At the time of the author's assessment of the project, a decision on a pilot plant was urgently required if sales were to be built up before patent protection expired. A breakthrough in process R_2 had been made and it had been shown that both R_1 and R_2 offered prospects for profitable production. It was clear however that operations at pilot scale could not be expected to show a profit.

The situation might be termed 'classical' in new product research. The pilot plant was required to produce quantities of product for market development - this was the only way to obtain reliable information concerning the profitability of the full-scale plant. However to obtain the funds to build a pilot plant a convincing case had to be presented, but this required market data that was not available without pilot plant operation. In these circumstances a vicious circle can develop, time is lost, and eventually external circumstances dictate the decision to be taken. This situation may sometimes be broken by a strong personality who is prepared to back the project. The term 'project champion' has been used to describe such a person - Schon (29), gives some examples. The resolution of this type of dilemma is achieved, at least in part, by the demonstration of the possible returns and risks in the manner to be described.

4.2 The Alternative Courses of action.

The analysis considered eight alternatives, these are presented in Figure 4.1. Two involved terminating work on the product: either by stopping completely or by transferring work to another Division of ICI. (For a variety of reasons, if a plant based on route R_2 was preferred, it could have been advantageous to transfer production of the product to Division Y.) The other six alternatives were different variations on a common theme. Each required that small scale production facilities be built immediately to be followed, if market development was successful, by a full-scale plant. Three alternative courses of action were considered for each of the two routes to the product:

(1) That the control of the project be transferred from R & D Department to a Division Product Group.

(2) That the project remain under the control of R & D Department.

(3) That the control of the project remain in R & D Department but that the initial demand for the product be met from a rudimentary plant (assembled from existing equipment), to be followed after one year by a pilot plant.

The differences between alternatives 1 and 2 include the methods used to account research expenditure and the works site of the pilot plant. (The two works in question had different facilities and spare equipment that could be usefully adapted to the needs of the pilot plant).

The decision boxes in the later years of the project indicate that the project could be stopped before resources were committed to a full-scale plant, if market development was unsuccessful. Timing played an important part in the choice of the set of alternatives. The minimum times required to design, build, and run the pilot plant, and the time to build the full-scale plant, ensured the date of commissioning of the latter could not be before the beginning of year 6. The possibility of commissioning the full-scale plant after the beginning of year 7 was not considered because of the imminence of the date at which patent cover would run out.

4.3 The Evaluation.

The system requires that each of the alternatives be evaluated in the manner described in Section 3.3. The evaluation of the full-scale plant of alternative 1 is now discussed in detail. Figures 4.1 to 4.12 present the basic data, and results of the evaluation. (For convenience these figures are collected at the end of the Chapter). Points related to the derivation of the data and interpretation of the results, are dealt with in the Discussion (Section 4.7).

4.3.1. The Viability Checklist.

Figures 4.2 and 4.3 present the completed checklist for the first alternative of Figure 4.1. It is evident that, as far as raw materials and plant were concerned, no 'major problems' or 'major threats' were exposed. This was perhaps not very surprising, almost all the raw materials are under ICI control, and at the time of assessement, the route R_1 was at an early stage of development. No doubt as process definition was continued, some 'major problems' or 'major threats' would emerge. It is well to note in passing, that entries in the 'ignorance' column might well hide 'major problems' or 'major threats'. It is important therefore to treat such entries with the same respect as entries in the 'major threat' column until such times as the ignorance is resolved.

Amongst the product and market factors, cost-benefit, large scale testing and promotion, were shown to constitute 'major problems'. The first two were closely-related - large scale testing was the key to establishing the benefit part of the cost-benefit ratio. The factors were entered as 'major problems' because cost-benefit was considered to be an important determinant of the product's selling price, and as the sensitivity analysis shows (Figure 4.11) the eventual profitability of the project was strongly dependent on selling price. Promotion was rated a 'major problem' as it seemed clear that a considerable campaign would have to be mounted to overcome the traditional caution of the customers in question. (The adoption of the new product required the customer to make slight changes to his production philosophy).

It is interesting to note that the checklists associated with all six of those alternatives which assume Mond Division continued the project, were almost identical. The differences stemmed only from the process to be employed, as essentially the raw materials used and the properties of the product produced by each alternative were the same. The checklist referring to alternative 1 therefore applied equally well to alternatives 3 and 5 that also were based on route R_1.

The checklist covering the process factors of alternatives 2, 4 and 6, (employing route R_2) is presented in Figure 4.4. The more advanced state of the process is immediately evident - the assumptions are more precise, there are no entries under the 'ignorance' heading, and apart from the reaction stage all the factors were considered to fall within the classes 'no problem' or 'minor problem'. The reaction stage was entered as a 'major problem' because a raw material conversion efficiency of $\sim$ 85% was judged to be the minimum acceptable for large-scale production. At the time of assessment however the best conversion efficiency obtained in the laboratory was $\sim$ 65%, and this seriously reduced the expected return of the large-scale plant. However a number of methods of reaching the 85% target were felt to be possible and further laboratory research was in progress.

4.3.2 The Financial Evaluation.

Once again the full-scale plant of alternative 1 is considered in detail. The basic data in the 'as of now' situation is presented in Figures 4.5 and 4.6. It should be noted in passing that the mode value of all the variables in the financial evaluations of project M (and also project N discussed later in this chapter) was assumed to lie midway between the associated 95% confidence limits (see Section 3.5.) Furthermore it was assumed (referring to Figure 4.6) that in years 2, 3 and 4 the demand would be met from the pilot plant and the research and other costs allocated to it. The most striking feature of the data is the magnitude of the uncertainty. For example, the 95% confidence interval on the capital cost was estimated to be ± 40% of the mode value. As was made clear in the 'assumptions' column, this was because the process had been investigated at only laboratory scale, and the cost was extrapolated from plant items, sized and costed, for a plant of capacity approximately midway between the pilot and full-scale plants. The variables subject to greatest uncertainty were those defining sales volume and selling price. At the time of assessment there had been very little market development and therefore estimates were extremely tentative. The new product was a treatment for a commodity well defined in tonnage terms. Uncertainty centred around (a) the application rate of the new product and (b) the penetration of the potential market. In the optimistic case, the whole of the U.K. market was assumed to be penetrated by year 9. The selling price was estimated by (a) determining the increase in effectiveness the customer might expect to achieve, by application of the new product, and (b) by assessing the amount the customer would pay for a benefit of £1. The very considerable uncertainty in selling price was due to both of these factors. The effectiveness increase was estimated to be between 7% and 20%, and the customer was estimated to be prepared to pay between 6/8d. and 10/0d. for a benefit of £1.

The formula for calculating the variance of a function of several variables (see Appendix 4, Section 2), was used to convert some of the basic data into the form required by the computer programme (see Section 3.5). For example the programme was written to accept the raw materials cost of the plant as a single variable. The appropriate 95% confidence interval was determined by applying the above rule to the basic data - the 95% confidence intervals on the conversion efficiency and unit cost of each raw material.

The data in the 'after research' situation is presented in Figures 4.7 and 4.8. Members of the project team were asked to make estimates of variables at the point in time when a decision on a full-scale plant is required (see Figure 4.1). In the case of alternative 1, this point was at the end of year 3. The point was chosen because one of the main objectives of further research in the laboratory, on small-scale plants, and in the market was to refine the information upon which the decision to build the full-scale plant would be based. The 'after research' situation therefore provides a picture of how the prospects of the project could look after a period of research. It is made clear that the figures required were not to represent the best possible outcome of research, or turn of events in the market, but what might reasonably be expected to materialize. Thus for example, the 95% confidence interval on capital cost was assumed to be reduced from $\pm$40% in the 'as of now' situation to $\pm$10% in the 'after research' situation. Similarly, it was considered that further research would lead to an increase in the raw material conversion efficiencies. The efficiency in the 'after research' situation was therefore taken to be 10% above that of the 'as of now' situation.

Following the procedure described in Chapter 3, the risk analysis programme was applied. Figure 4.9 presents the cumulative cash flow of the pilot plant of alternative 1 over a four year period: one year for building and three years for operation. This is included for completeness, to show that it would be most unlikely for the pilot plant to achieve a positive NPV within the forseeable future. The upturn of the cash flow in year 5 is rather misleading, as this was entirely due to credit given to the freeing of working capital. (This amounted to about £45 k in the case when the expected values of variables were achieved). Figure 4.9 also includes, for each year, the frequency distributions produced by the 100 simulations used in the calculation. These may be used to draw probabilistic conclusions concerning the NPV of the project. For example, at the end of year 5 the probability of a NPV $>$ -£100k is 0.12 (i.e., (6 + 5 + 1)/100). Similarly, at the end of year 3 the probability of a NPV$<$-£180k is 0.05(i.e., (4 + 1)/100).

Figure 4.10 presents the return and uncertainty of the full-scale plant in both the 'as of now' and 'after research' situations. It is evident that by the end of year 11, even in the 'as of now' situation, there was a probability of $\sim$ 0.85 of a positive NPV. Assuming the distribution of the project return in year 11 is approximately normal, the chance of the return lying outside standard deviation limits is

~30%, and thus the chance of it lying above the lower limit is ~85%. The above calculations do not include the expenditure on research and pilot plant operation prior to commissioning of the full-scale plant (estimated at ~£164k). The distribution of return showed the probability of a positive NPV, inclusive of expenditure on research and pilot plant operation, to be reduced to ~0.61. If research and pilot plant operation yield the returns estimated in the 'after research' situation, then the Figure shows the NPV of the full-scale plant in year 11 to have been increased from £276k to £350k and the uncertainty surrounding the return to be reduced substantially from £276k to £100k. (Assuming, once again, uncertainty to be the standard deviation of the distribution of project return.)

The results of the risk analysis are summarized in Figure 4.11, the upper part of the Figure expresses return of the project in the 'as of now' situation in terms of NPV and several other well known criteria: DCF rate of return, payback period, and return on capital. The values of these other criteria confirm the impression given by the NPV calculation: that the full-scale plant of alternative 1, even in the 'as of now' situation, looked promising on financial grounds. The lower part of the figure is devoted to a sensitivity analysis. The mechanics of the analysis are described in Section 3.3.2. It is clear that the project return and uncertainty were most sensitive to changes in the variable: 'selling price in the UK market'. A change of 10% in the mean value of this variable changed the mean value of the return by almost twice as much as equal changes in the mean value of other variables. The effect of this variable on the uncertainty was even more dominant - an order of magnitude greater than the effect of any of the other variables. To reduce the uncertainty surrounding the project return substantially it was obvious that the selling price, particularly in the UK market, would have to be better defined. The rankings in the sensitivity table show that in general, the importance of a variable with respect to increasing the project return is different from its importance with respect to uncertainty reduction. For example, 'variable operating cost' ranks third in the return column and seventh in the uncertainty column.

4.4 The Choice of Alternative.

The results of the financial evaluations of four of the alternatives are presented in Figure 4.12. This summarizes the return and uncertainty of the full-scale plant in each of the alternative 'as of now' and 'after research' situations. Only four of the alternatives were evaluated because after the comparison of 1 and 2, it became quite clear that route R_2 offered more promising prospects than route R_1. It appeared to be cheaper on capital (one less process stage was required) and also cheaper on operating cost. These points are reflected in Figure 4.12 by the higher return of alternatives 2, 4 and 6 over alternative 1. The checklist also tended to favour route R_2. In general far more was known of the process, and ways of resolving the problems concerning the reaction step were felt to be forthcoming (see Section 4.3.1).

The expected cost of research and pilot plant operation is recorded up to (a) the time at which a decision on the full-scale plant is required (this marks the 'after research' situation), and (b) the time at which the full-scale plant is commissioned. The cost of research incurred after the second of these points was included in the cost of running the full-scale plant. The differences between the above costs with respect to the four alternatives arose for a variety of reasons related to the process, the site, and the period of pilot plant operation. For example, the period of research and pilot plant operation was five years in the case of alternative 6 (compared with four years for the other alternatives). The differences between alternatives 2 and 4 (both employing the same process and with operation over the same period) were related to engineering practice. The pilot plant designed for alternative 4 was less expensive on capital, but more expensive on operating costs than that of alternative 2. The operating costs of the latter pilot plant were sufficiently low to promise a positive cash flow (£28k) over the period between the decision to build, and the commission of the full-scale plant.

In the case where the returns are expressed as inclusive of research expenditure (Figure 4.12), the uncertainty was obtained by summing the variances associated with the return of the full-scale plant and research expenditure. Suppose u_1 and u_2 are the uncertainties associated with the return r of the project (exclusive of research) and the expenditure on research e. (Where r and e are the mean values, and u_1 and u_2 the standard deviations of the respective distributions) The return of the project inclusive of research expenditure was then taken to be $(r - e)$ and the associated uncertainty to be $(u_1^2 + u_2^2)^{\frac{1}{2}}$ - see Davies (67), page 41.

The question of whether or not the planned period of research and pilot plant operation makes an adequate return is reflected in part by the difference between the 'ER - as of now' and 'IR - after research' situations (in the terms of Figure 4.12). Referring to alternative 1 for example, the figures are respectively £278k ± 281 and £186k ± 115. Thus in this case research is shown to have reduced uncertainty - but only at a high cost. As has been stressed on a number of occasions in this thesis, decisions are made after a consideration of checklists, financial evaluations, and any other information that might be available. At the time the author assessed project M, the possibility of going ahead with the project without further research and pilot plant operation was not considered. This was because of the level of risk involved - not all of which could be included in the financial evaluations. The main basis for comparing the financial prospects of the alternatives was therefore taken to be the 'after research' situation inclusive of expenditure on research and pilot plant operation (i.e. the 'IR - after research' case).

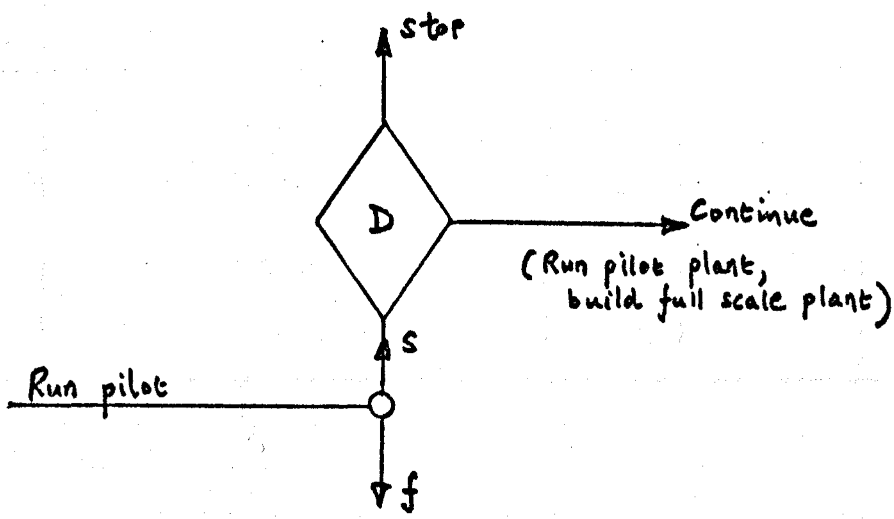
There was clearly little to choose between the financial returns promised by alternatives 2, 4 and 6. Alternative 4 showed the highest return, and alternative 6 the lowest uncertainty. Given the dimensions of the uncertainty however, the differences are not very significant. In cases such as this, it might be helpful to make some further calculations. For example, the assumption could be made that a low sales volume would be achieved and the effect of this (and other calculations), on the comparison examined. With respect to alternatives 2, 4 and 6 however, which were all minor variations of the same theme, this step was not considered to be helpful. It is well to accept that there is sometimes a limit to the amount of analysis that can usefully be done. Given a series of comparable candidates, the best policy is often to select according to intuition or even the toss of a coin, and then to make good the choice, rather than to waste time and effort in attempting to establish a supposedly optimum course of action. (This is the gist of the thinking expressed by Baines, Bradbury and Suckling ((5) page 132).) In the latter vein, one of the views expressed was that either alternatives 2 or 4 should be preferred since only one pilot plant had then to be commissioned. Likewise alternative 6 might have been chosen because it provided the opportunity of an additional period of delay before expenditure on the pilot plant.

Though the three alternatives employing route R_2 offered a reasonable expected project return - even after covering the costs of research and pilot plant operation, the high costs caused concern. One of the factors contributing to this situation was the possibility of the occurrence of an unexpected event that could undermine the basic assumptions of the risk analysis. Before leaving the question of 'choice' it is relevant therefore to consider the 'stop' options more carefully. After a period of pilot plant operation for example, it might be decided to stop the project because a variable is shown to take a value at the pessimistic end of its associated 95% confidence range. If it was found that the effectiveness increase that product M could offer customers was $<8\%$, then it would be difficult to justify continuing the project. The selling price obtainable would then probably have been below the minimum level required for running the full-scale plant at a profit.

In contrast to the above, in which an event might stop the project was foreseen (by the distributions of selling price input to the risk analysis programme), the project might also be terminated by an event unforeseen at the time of assessment. The results of

Figure 4.12 are thus dependent on the basic assumptions continuing to hold. For example that over the period covered by the evaluation (a) competitors will not introduce markedly superior products, (b) restrictive legislation will not be imposed, and (c) the plant will function in the desired manner. The design of the viability checklist should clearly be suited to drawing attention to possibilities such as those listed above.

The effect of an unforeseen event may be examined by making a slight elaboration of the tree network. For example, referring to project M, the stop option (Figure 4.1) immediately before the decision to build the full-scale plant may be re-drawn in the way illustrated below:-



The letter f denotes situations where unforeseen events cause the project to be terminated with the consequent loss of expenditure on research and pilot plant operation. The letter s includes all other situations that can occur. The maximum probability of an event f such that the expected value of the return of the alternative is positive may then be calculated. If the probability of occurrence of f is p, then the maximum value of p, such that the return of alternative 1 is positive is given by:

$$-150 + 336\ (1-p) = 0, \text{ thus } p < 0.55.$$

In the case of alternative 1, Figure 4.12 shows the cost of research and pilot plant operation prior to the decision to build a full-scale plant to be £150k. After this point the combined income from the pilot plant in years 3 and 4, and full-scale plant operation is £336k. (The former makes a loss of £14k and the latter a gain of £350k.) The corresponding figures for the other alternatives are presented in the Table below.

Alternative	Expected cost of Research and Pilot Plant (Before the decision to build the Full Scale plant)	Expected Return		Total	p
		Pilot Plant	Full-scale Plant		
1	150	-14	350	336	0.55
2	148	28	516	544	0.73
4	98	- 6	516	510	0.81
6	128	27	473	500	0.74

Given the checklist ratings the values of p were felt by those concerned with project M to be sufficiently high to warrant further research, especially on alternatives 2, 4 and 6.

In the event however, it was decided to follow alternative 7; the decisive factors were the emergence of R_2 as the most promising route, and the point that Division Y was about to sanction the building of a multi-product plant. This plant could be readily modified to incorporate the R_2 route and hence to produce quantities of the new product. Indeed it appeared that for a small additional capital cost, the plant could be readily adapted to meet the entire demand for product M during the market development phase. This advantage was considered to be sufficiently attractive to warrant Division Y continuing the research programme.

With the transfer of project M the author's direct interest in the project ceased. For reasons of convenience, it was advantageous to restrict attention to Mond Division projects. The procedures for monitoring progress are therefore illustrated by reference to project N.

4.5 Project N.

Project N was initiated when details of new technology, related to one of Mond Division's traditional products, appeared in the patent and technical literature. The product was an intermediate and was used captively within the Division. The demand for the final products had been increasing steadily, and it was thought that it might be possible to use the new technology in a future expansion of capacity for the intermediate.

Though the claims in the literature were attractive, there was insufficient evidence to justify an immediate start on laboratory research. The first stage was therefore a paper study of possible processes to the intermediate. One of these processes (route k) appeared to offer significant advantages over an improved version of the existing process (route J). The latter was a simple scale-up of the major plant items and was accompanied by the usual economies of larger scale operation. It was calculated that the capital cost of a new plant employing route K, would be greater than that of an equivalent plant based on route J. However it was also evident that over a period of several years operation (< 10), the additional capital costs, and research costs associated with route K, could be adequately recovered by the reduced operating costs and maintenance procedures of the route.

A broad outline of the envisaged research programme is presented in a simple bar chart (see Figure 4.13). The initial paper study is shown to be followed by a period of 9 months process definition in the laboratory. If this were successful, further process definition at both laboratory and semi-technical scale would be necessary before the building of a full-scale plant. The bar chart also indicates the future decision points, and provides an estimate of future research expenditure. The importance of the decision to be taken at the end of year 1 is highlighted by the sudden rise in the expenditure profile in year 2. The decision to continue project N at this point commits approximately half the total research expenditure, to the building and running of a semi-technical plant.

4.6 Monitoring the Progess of Project N.

This section reports on the evaluation of project N at times T_1 and T_2 (see Figure 4.13). The objective is to show how the checklist entries, and the plot of the financial position of the project, enable the 'control' step of the cycle (Figure 3.1) to be performed. The two methods of monitoring progress are discussed in Section 3.4.

4.6.1 The Evaluation at Time T_1.

It is evident from the bar chart that the evaluation at time T_1 was made on the basis of the available literature, the paper study, and experience of the existing process to the intermediate. (The basic raw materials and, of course, the final product were shared by routes J and K).

The factors of the viability checklist used to assess route K were a sub-set of those used with project M (see Figures 4.2 and 4.3). All the factors concerned with raw materials and process were included, but as the intermediate was to be used captively within Mond Division only 'product quality' of those factors under the head product and market needed to be assessed.

The checklist entries at time T_1, are illustrated in Figure 4.14. Raw material supply was shown to present a 'major threat' in the long term, with the implication of a trend to higher prices and poorer quality. No 'major threats' were evident in the factors concerned with the process, though corrosion and the reactor section were entered as 'major problems' and process hazards was classed as an area of 'ignorance'. The isolation section of the plant was also expected to present difficulties, but it was discovered that a possible scheme had been patented. The factor was classed as a 'minor problem' as it was felt that at worst, the patented isolation system could be cheaply licenced. When the project involves an intermediate, it is important to bear in mind that other parts of the business will also be affected by the outcome of events. The checklist ratings should clearly take these considerations into account. It is possible therefore for a similar corrosion problem to be rated as a 'minor problem' in the case of a new product project, but as a 'major problem' in the case of a project concerning an intermediate for existing manufacture.

The financial evaluation of the project was made by calculating the NPV of the income attributable to manufacture of the intermediate on a new plant. Firstly it was assumed that the plant was based on route J and secondly that the plant was based on route K. The difference between these evaluations was taken to be the benefit or advantage offered by further research expenditure. Both calculations were taken over a ten year period from the commission of a full-scale plant in year 6(see Figure 4.13) and all incomes and expenditures were discounted back to year 1 at a rate of 15%. The production requirements from the new plant were assumed to be those given in the Table below:-

Year	6	7	8 to 15
Production (kton)	7.5	12	15 (plant capacity)

It was assumed that requirements of the intermediate in excess of the above figures would be met from the existing plant and that over the period, the transfer price of the intermediate would remain constant at £60/ton. To emphasize the differences between the processes, the variables related to income (i.e. transfer price and production) were assumed to be known with certainty.

The data concerned with the costs of route K in the 'as of now' and 'after research' situations is presented in a condensed form in Figure 4.15. Once again, the 'after research' situation was assumed to be that existing immediately before the decision to build a full-scale plant.

As proposed in Section 3.4, the returns and uncertainties of the major alternatives (routes J and K) were plotted in the 'as of now' and 'after research' situation (see Figure 4.18). As only small changes from the existing plant (costing $<$ £10k) were expected if route J was adopted, the 'as of now' and 'after research' situations were not distinguished, and the results of only the latter were plotted. The evaluations made at time T_1 are indicated by the suffix 1 in Figure 4.18. All the costs associated with research are included in the evaluations. It is evident that at time T_1, a plant based on route J was considerably more attractive than a plant based on route K, given the assumption of the 'as of now' situation. This was because the scant information concerning the process only permitted a 50% yield on the principal raw material to be estimated.

The benefit offered by further research is demonstrated by the difference between the return of route K in the 'after research' situation and the return of route J. The Figure shows that even including the costs of the necessary research and semi-technical plant, the return from a plant based on route K could exceed that of a plant based on route J by $\sim$ £250k, though the uncertainty associated with route K would remain slightly greater than that of route J.

A further point, which must be stressed, is that the technology behind route J was already well proved. The evaluations of route K, in both the 'as of now' and 'after research' situations are each dependent on the operational viability of the process - which at times T_1 and T_2 was designed almost exclusively from theoretical considerations.

4.6.2 The Evaluation at time T_2.

The main effort in the laboratory during the period T_1T_2 centred on an investigation of the basic reaction mechanism. Testing under a variety of conditions revealed that the high raw material conversions claimed in the literature could be reproduced - at least at a very small scale. In the course of this work, appropriate analytical methods were developed for measuring the parameters determining reaction efficiency. It was also found that corrosion would present a number of severe problems, thus confirming the checklist rating given to this factor at the time T_1 (see Figure 4.14).

In parallel to the laboratory work undertaken by a team of chemists, a chemical engineer was responsible for a more detailed examination of the process as a whole. This involved a closer look at the individual unit operations, and the configuration of the plant.

It was found to be possible to streamline the original plant design in a number of areas. The size of reactor, the number of adsorber units, and the size of the refrigeration section were all reduced. It was also concluded that a duplicate reaction system, included in the first design as an installed spare, would not be necessary. Furthermore a second reaction system (Q_2) different in both design and operating conditions to the initial system (Q_1) was considered. The Q_2 reactor was closer to Mond Division's existing technology than was the Q_1 reactor.

Another important finding of this work concerned the isolation stage of the process. Contact was made with the organisation responsible for patenting a possible system. It was discovered that the proposed method was not very suitable for the scale of operation planned by Mond Division and thus could only be considered as a 'last resort'. The findings of the above research work are reflected in both the checklist ratings and the financial evaluation of time T_2. Figure 4.16 presents the changes in the checklist ratings, the convention is to identify the ratings at times T_1 and T_2 by the integers 1 and 2 respectively. The assumptions column gives emphasis to recording the changes in thinking that took place over the period T_1 T_2.

It is clear from Figure 4.16 that there was no change in the situation concerning the long term threat to the raw material supply. Nor was there any change in the assumptions with respect to the factors control, process operation, or patent position. The research in the laboratory enabled the 'minor problem' rating of the analysis factor to be shifted to one of 'no problem', even allowing for some further work to speed up the methods devised. Though laboratory research work confirmed the high raw materials conversion efficiency quoted in the literature, no change in the 'major problem' rating of this factor was felt to be justified at time T_2. This was because numerous problems of reactor design remained; indeed some could only be resolved after a period of semi-technical scale operation. The research work also confirmed corrosion to be a 'major problem'. Experience in the laboratory had been such that a change of rating from 'major problem' to 'major threat' had been considered. The former rating was retained because some hitherto untried methods of containment were felt to be suitable.

The rating attached to the isolation stage of the process was moved from 'minor problem' to 'major problem' because the amount of further research necessary in this area was felt to be significantly greater at time T_2 than at time T_1. The chemical engineering work was also largely responsible for the other changes in the checklist. The ratings of the factors purification stage, product quality and effluents were moved from 'minor problem' to 'no problem' and the rating given to hazards was changed from 'ignorance' to 'minor problem'.

The research work also enabled new estimates of the variables in the financial evaluation to be made. The estimates at time T_2 of the capital and operating costs, of a process using the Q_1 reactor system, are summarised in Figure 4.17. The Figure shows a number of changes to have taken place - only the estimates of the fixed operating cost were the same at both T_1 and T_2. The capital cost of the plant was reduced, though without further definition the range given to the 95% confidence intervals remained the same (in % terms) for both the 'as of now' and 'after research' situations.

Laboratory research confirmed the high raw material conversion yields claimed in the literature. However the overall yield of raw materials in the 'as of now' situation was only increased from 50% at T_1 to 60% at T_2, as no practical work on the isolation of the product had been completed. The evaluation at time T_2 also showed the part of the variable cost covering other raw materials, variable services and effluent disposal to have increased from £7/ton to £10/ton. This change was largely a result of streamlining the process to achieve a capital cost reduction.

The figures for a plant using the Q_2 reactor system are not recorded, but both the capital and the variable operating costs were greater than the corresponding figures for the Q_1 reactor.

The simple bar chart (Figure 4.13) was also revised at time T_2. Forecasts of Mond Division's demand for the intermediate at time T_2 indicated that further capacity would be required during year 4 rather than at the beginning of year 6, as anticipated at time T_1. As there was insufficient time to design and build a plant based on route K to meet a date in year 4, it was concluded that the earliest date for commissioning a plant based on the new technology would be the middle of year 7. An extra year and a half of research was therefore available if required. A further change in the network was a three month delay in the steps to design, build, and operate the semi-technical plant. This was to enable the latter part of year 1 to be devoted to the isolation stage of the process. Nevertheless the estimate of the future cost of research was reduced from $\sim$ £300k at time T_1 to $\sim$ £240k at time T_2.

Figure 4.18 shows how the changes discussed above are reflected in the financial evaluation of the project. At time T_2 it appeared that the plant would be built in years 5 and 6. The ten year period of operation was therefore assumed to cover years 7 to 16, but as before the cash flow was discounted back to year 1. This, and a slight adjustment in one of the fixed costs, was the reason for the slight change in the return, attributable to route J. Referring to the version of route K employing the Q_1 reactor, it is clear that on the basis of the simple model, the prospects for the route showed a marked improvement in both the 'as of now' and 'after research' situations. If the original reactor design (Q_1) was employed and functioned in the manner expected, then the advantage of route K over route J increased from ~£250k at T_1 to ~£400k at T_2, in the 'after research' situation. The reduced capital cost and the increase in raw material yield estimated at time T_2 also had the effect of substantially improving the expected return of a process based on route K in the 'as of now' situation.

The Q_2 reactor system is also shown to present an attractive target of ~£250k. Though less than that of the Q_1 system, a plant based on the Q_2 design would have the advantage of operating at less severe conditions closer to the range within the existing experience of Mond Division.

Though both the checklist and financial evaluation illustrated and reflected the implications of a number of changes in the standing of project N, none were considered to be sufficient to require a major change of plan. At time T_2 the factor that most likely would have given rise to a change was the financial advantage of route K over route J. If over T_1T_2, this had dropped significantly (e.g. by >50%), it is likely that the future research programme and, indeed, the project as a whole would have been reassessed. It was shown that this situation could have arisen (a) if the laboratory experiments had yielded raw material conversion efficiencies of $\sim$70% (compared with the 90% claimed in the literature), or (b) if at time T_2 the estimate of the capital cost of the plant (at T_1) was increased by $\sim$ 20%.

In the event, the research programme over the latter part of year 1 was revised slightly to give greater emphasis to the problem of isolating the product.

4.7 Discussion.

The Discussion is devoted to some of the general points that emerged during the application of the system, and to the approach.

4.7.1 The alternative courses of action.

Projects M and N were similar to the extent that at the time of assessment, the alternative courses of action were reasonably clear. There was no call therefore to resort to 'critical examination' (see Section 3.2), or similar techniques. Project N would have provided an example if at time T_2 the financial advantage of route K over route J was substantially reduced. It had been decided that if necessary a critical examination would have been initiated to generate possible means of reducing costs.

An important problem was found to be the translation of the alternative courses of action into a decision tree. With respect to project M for example, the number of branches in the tree (Figure 4.1) could have been increased by supposing pilot plant operation was for a year longer or for a year shorter than was supposed. In this event, the number of branches would have been extended from eight to twenty. (Two variants of each of the six Mond Division 'continue' branches would have been added). Similarly by including the decision whether to market exclusively in either the home market, or the export market, in addition to the marketing in both (as was assumed), the number of branches would have been increased from 20 ($(3 \times 6) + 2$) to 56($(3^2 \times 6) + 2$).

The policy adopted was to restrict the number of alternatives considered, and to present the situation in the simplest terms. In the case of project M, the possibilities of commissioning the full-scale plant before the beginning of year 6 or after the beginning of year 7 were rejected on grounds of the timing of the engineering effort and the patent situation (see Section 4.2). On the other hand the various markets that might be developed, or selling prices charged, were reflected in the distributions fed into the risk analysis programme.

4.7.2 Project evaluation: the viability checklist and financial evaluation.

It was found to be necessary to complete the checklist after joint discussion between the author and all those responsible for running the research and marketing sides of the project (perhaps three or four prime movers). The need for a consensus, or agreed approach, was brought out when assessing project M. Two members of the project team were invited to complete, independently, the part of the checklist concerned with product and market. It was clear that one of the assessors was consistently more pessimistic than the other. The differences were usually of degree rather than of fact. For example, the factor cost-benefit (rated a 'major problem' in Figure 4.11) was rated a 'major threat' by the second assessor. Some of the differences were considerable however. The factor uniqueness was rated as 'no problem' by the first assessor but as 'major threat' by the second assessor. This was owing to the introduction of a new product by a competitor. Both assessors were aware of the move, but clearly attached different weights to the impact of the development on Mond Division's product. Discrepancies of this extent illustrate the value of the 'assumptions' column in which the checklist entries must be qualified by relevant comment.

On some occasions it may be possible to avoid the need to rate factors by making a cash estimate of the losses that might accrue in the event of continued non-resolution of the problem or threat. Thus for example instead of rating effluents a 'major problem', the entry could read: 'If the effluent problem is not solved, the increase in variable cost could be £15/ton - over the period of the financial evaluation this would reduce the NPV by £500k'. It is proposed to investigate this point further in the future as a means of estimating the effect of individual problems and threats on the project return.

Turning to the financial part of the evaluation, estimates of the mode and 95% confidence interval were made by members of the project team after consultation perhaps with expert opinion. Quite often the immediate reaction of those providing the information was to ask to be reminded of some of the principles of statistics. It was found that a preliminary session centred on some basic concepts such as mean, mode, median, standard deviation, confidence interval, normal distribution etc., provided a useful prelude to further discussion. It was also found to be helpful to draw respondent's attention to (a) the 1 in 40 chance that the variable will exceed the upper, or fall below the lower, 95% confidence limit and (b) that if the variable is assumed to be distributed normally, the 95% confidence limits are approximately four standard deviations apart. In none of the projects assessed were devices such as Schlaifer's standard lottery (see Section 1.3.1) systematically applied.

The reliability of data estimates depends to a considerable extent on the availability of a store of past data relating forecast to achieved values. If for example, it is necessary to estimate the capital cost of a full scale plant from laboratory information, then ideally the estimate should be adjusted in the light of past forecast and achieved values of the capital costs of similar plants. In general this information was not readily available. Nevertheless, it was considered preferable to work with variables expressed in terms of probability distributions even though the distributions were often rather tentative. An important reason for the lack of data is the time lag between making the estimate and discovering the achieved value of the variable. In the case of a plant, the first estimate of the capital cost can be up to five years before construction is complete and the achieved cost is learnt. Similarly market forecasts often extend some 10 to 15 years into the future. A related factor is the job continuity of the persons making the estimate. Over periods such as those mentioned above there is a good chance that the person making the estimate will have changed job before the achieved value of the estimate becomes known. One of the advantages of adopting a system such as that proposed by the author is the base of information that regular application will assemble.

No difficulty was experienced in eliciting estimates of data in the 'as of now' and 'after research' situations. It was evident that respondents were familiar with thinking in these terms. It had been common practice for example to calculate operating costs based on raw material yields that had already been achieved in the laboratory, and yields that might eventually be obtained after further research. On some occasions in the past however, the variables had been expressed in terms of one or the other of these estimates. It was also found that the reduction in the uncertainty that might accompany research expenditure was not normally estimated.

4.7.3 The output of the system.

The checklists, graphs and tables that formed the output of the system were readily understood, and were usually well received by those responsible for project management. Nevertheless some disappointment with the output of both the checklists and risk analysis was also expressed.

The checklists were criticised by some managers for asking some 'obvious' questions (by which they meant questions with obvious answers). A further criticism was that there was insufficient space in the assumptions column to do justice to some of the issues raised. It is hoped to resolve these problems in the future by ensuring the recipients of checklists are well aware of the inherent limitations. Firstly by attempting to bring a reasonably complete set of relevant points to management's attention, the checklist is clearly very susceptible to asking the 'obvious' question. However, in general, the questions with obvious answers cannot be specified in advance (if indeed answers are ever obvious, except to the prejudiced). Moreover this minor irritation is a small price to pay for raising questions that are not so obvious or that would have been forgotten. Secondly, the checklist is an incomplete form of reporting and must be supported by additional material providing information in depth where appropriate.

The criticisms of risk analysis were of a rather different nature. After going to the trouble of providing estimates of mode values and confidence intervals, some expected that a clear-cut decision situation would emerge. The opposite was usually the case, the distributions reflecting the returns of each alternative often overlapped to a large degree, thereby emphasising the similarity rather than the difference between the returns offered.

Another point of contention was the amount of information generated by the system. Some managers would have preferred the information to be expressed in a more condensed form, however, there was no consensus on this point. Very often much of the data is common to more than one alternative. In project M for example, the same market data was common to each alternative. The difference between the alternatives were confined to the building schedule, the process to be used, and the siting of the pilot plant.

Most of the managers concerned with the projects assessed by the author were already well aware of the value of sensitivity analysis. The possibility of generalising the results was a question that often arose. A typical question was: 'given that a 10% change in capital cost changes the mean NPV by £30k, what change in NPV is produced by a 7% change in capital cost?' Methods of extending the results of the sensitivity analysis by interpolation and extrapolation were investigated - the results of this work are reported in Appendix 4.

The two methods of monitoring progress using the checklist ratings and the return-uncertainty plot, were found to be convenient means of demonstrating the changes in the 'state' or prospects of the project. In common with the results of the risk analysis calculations however, the methods did not of themselves resolve the manager's problem. At the 'control' stage of the cycle, the problem is to recognise when changes are sufficiently large to warrant a revision of plan. (This may include, of course, terminating the project.) In other words the problem is to decide when the 'problem identification' step of the cycle (Figure 3.1) has been reached. When changes are substantial, or where a strong underlying trend has been established, this point may be clear. But in general, 'problem identification', like 'choice' is largely dependent of the judgment of the management team.

FIGURE 4.1: NETWORK OF THE ALTERNATIVE DEVELOPMENT POLICIES. - PROJECT M

DATE (YEAR)	1	2	3	4	5	6	7

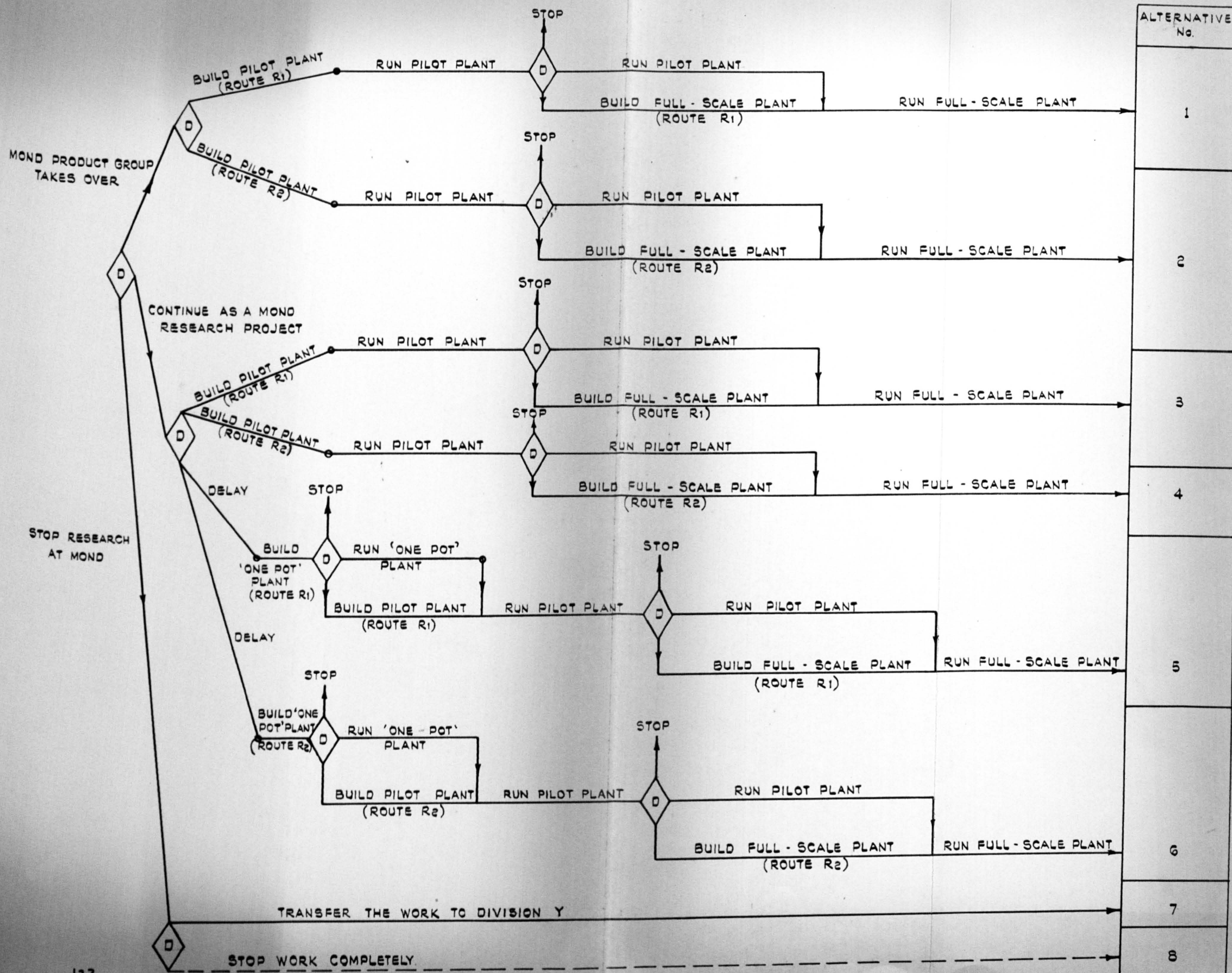


Figure 4.2: Viability Checklist - Project M (Alternative 1 - Process R_1)

Factors	No Problem	Minor Problem	Major Problem	Major Threat	Ignorance	Assumptions
Raw Materials						
Security of Supply	✓					Only one of the raw materials is outside ICI control; no problems are anticipated
Price Trends					✓	Price trends over the last few years have been steady - the future has not been considered in detail.
Hazards	✓					The raw materials present no hazards over and above those normally experienced in the chemical industry.
Quality	✓					No problems are anticipated.
Process						
Corrosion					✓	Not investigated outside the laboratory.
Control		✓				A fine temperature control is required on the second stage of the process. This requires further investigation.
Analysis					✓	Have not investigated outside the laboratory.
Reaction Stage					✓	"
Purification Stage		✓				Two forms of the product are produced: A and B. Only form A is suitable. It might be necessary to develop a separation treatment.
Isolation Stage						
Effluents		✓				Effluents are such that they will have to be bulked and deposited at sea.
Hazards		✓				There is a slight dust explosion hazard that must be controlled.
Process Operation		✓				There are several filtration steps in the process that could be time consuming and so reduce throughput.
Patent Position	✓					Patents concerning the effect are strong and provide cover for several years. The position of the process is weak.

Figure 4.3: Viability Checklist Continued.

Product and Market Factors	No Problem	Minor Problem	Major Problem	Major Threat	Ignorance	Assumptions
Uniqueness	✓					The effect produced is quite novel. A product with a similar but much inferior effect has recently been introduced by firm Q.
Quality	✓	✓				The particle size of the product will have to be closely controlled.
Cost-Benefit			✓			A considerable amount of further research will be required to establish the rate of application of the product.
Hazards	✓					All tests so far suggest no problems.
Customer Identification						The company (ICI) already sells a number of lines to the potential customers.
Compatability with Customer's Equipment		✓				It might be necessary for customers to adopt a slightly different method of working.
Obsolescence Rate		✓				Always a problem in the field of interest. A strongly competitive product is unlikely to emerge in the short term.
Approval for Use	✓					Tests are being made under the auspices of the UK body with responsibility for the authorising sale of the product.
Promotion			✓			The potential customer is noted for his cautious approach. The new product will require a slight change of philosophy on the part of the customer.
Large Scale Testing			✓			Though facilities are available, the nature of the effect presents many difficulties.
Technical Service	✓					The Division with responsibility for sales have extensive facilities and considerable experience in this area.

Figure 4.4: Viability Checklist - Project M (Alternative 2 - Process R_2)

Process Factors	No Problem	Minor Problem	Major Problem	Major Threat	Ignorance	Assumptions
Corrosion		✓				As mild steel reaction vessels are to be used, some problems are certain to arise, but these are not expected to be great.
Control		✓				It is necessary to achieve a precise control over the batch reaction temperature.
Analysis	✓					This was a major problem, the reactions are complex and the yield difficult to determine. The problem has now been overcome.
Reaction Stage			✓			The current yield on raw materials is $\sim$ 65%, the target value after further research is 85%.
Purification Stage)	✓					Two different forms of the product are produced and must be separated. A treatment has been found.
Isolation Stage)						
Effluents		✓				Much of the effluent can be disposed of via the local sewarage system. The residues have to be burnt, which will present some minor problems at larger scale.
Hazards	✓					Several of the materials present are highly inflammable, and the finished product could be susceptable to dust explosion. It is felt that adequate attention has already been given to these eventualities.
Process Operation		✓				Problems are not expected to be greater than those normally experienced operating new processes. Some further work will be necessary to prepare for large-scale operation.
Patent Position	✓					No possibility of infringement of other Company's patents. ICI's claim on the effect is strong, though the claim on the process is weak.

Figure 4.5: Full scale plant costs - Project M ('As of now situation'- Alternative 1)

Variable	Estimate of mode and 95% confidence interval	Assumptions			
Capital Cost (£k)	314 189 to 439	An x ton/yr plant is assumed, to be built during years 4 and 5 at Works w. The process is of 5 stages and based on a preliminary flow sheet for a plant of capacity y. (y was midway between the capacity of the pilot plant and x). The process has still to be defined in detail.			
Variable Operating Cost (£/ton)	131 116 to 146		Requirement/ton of product	Cost/Unit	Cost/ton of product
		Variable Services:			
		Steam	s_1, s_2, s_3*	c_1, c_2, c_3*	ct_1, ct_2, ct_3+
		Electricity	"	"	"
		Cooling water	"	"	"
		Raw materials:			"
		1	"	"	"
		2	"	"	"
		3	"	"	"
Fixed Operating Cost (£k/yr)	50.5 38 to 63		Requirement/year	Cost/Unit	Cost/year
		Fixed Services:			
		Heating	"	"	"
		Lighting	"	"	"
		Laboratory	"	"	"
		Process labour	"	"	"
		Maintenance	"	"	"
		Supervision	"	"	"
		Overheads	"	"	"

* The subscript 2 is assumed to refer to the mode value and the subscripts 1 and 3 to the 95% confidence interval.

\+ It was assumed that $ct_2 = c_2 s_2$, but (as explained in Section 4.3.2), the limits ct_1 and ct_3 were calculated using the formula for the variance of a function of several variables.

Figure 4.6: Annual Costs and Market Forecasts - Project M ('As of now' situation - Alternative 1)

Variable		Estimate of mode and a 95% confidence interval										Assumptions
Year		2	3	4	5	6	7	8	9	10	11	
Research Cost (£k)		7.5 6.0 4.5	7.5 6.0 4.5	7.5 6.0 4.5	7.5 6.0 4.5	7.5 6.0 4.5	6.0 4.5 3.0	6.0 4.5 3.0	6.0 4.5 3.0	4.5 3.7 3.0	4.5 3.7 3.0	The figures refer to research at Mond Division only. The mode sales assume an initial effort of n research scientists and their assistants.
Selling Expenses (£k)		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	These are nominal charges incurred by Mond Division; selling will be through another Division of ICI.
Other Costs (£k)		20.5 17.5 14.5	55.5 50.0 44.5	55.5 50.5 42.5	61.6 49.8 38.0	59.6 47.8 36.0	58.6 46.8 35.0	58.0 46.0 34.0	59.0 46.0 33.0	59.0 46.0 33.0	59.0 46.0 33.0	These are the market development, selling and research costs incurred by the Division selling the product.
Market 1 (UK)	Sales Volume (Ton/yr)	0 0 0	90 65 40	235 157 80	450 275 100	650 455 260	800 580 360	975 717 460	1000 780 560	1000 830 660	1000 880 760	These figures are assumed a concentration of y% is required to produce the desired effect. The optimistic forecast assumes the complete UK market is captured by year 9.
	Selling Price (£/ton)	0 0 0	75.0 45.3 15.5	→ → →								The upper figure assumes a product effectiveness of C_1%, and a customer prepared to pay £1 for a £2 benefit. The lower limit assumes a product effectiveness of C_2%, and a customer prepared to pay £1 for a £3 benefit.
Market 2 (Export)	Sales Volume (Ton/yr)	0 0 0	30 20 10	65 42 20	150 92 35	300 182 65	550 332 115	825 507 190	1000 645 290	1150 815 480	1230 975 720	Once again a concentration of y% of the product is assumed. The forecasts of market are with only the USA and EEC in mind.
	Selling Price (£/ton)	0 0 0	59.0 35.6 12.2	→ → →								These assumptions are the same as those for the home market with approximate allowances for tariffs and transportation.

Note: The pilot plant is assumed to satisfy demand in years 2 to 5 inclusive.

Figure 4.17: Plant Costs - Project N (Route K - Reactor System Q_1 - Time T_2)

Variable	Estimates of mode and 95% confidence interval	Assumptions
Capital Cost (£k)	'As of now' situation 730 550 to 910	A 15000 ton/yr plant is assumed to be built on a greenfield site at works W in years 5 and 6. The reduction in capital costs (from time T_1) is owing to (a) streamlining the process and (b) the decision not to include a second reactor system as an installed spare. No reductions in the $\pm$25% limits of the confidence interval can be made before semi-technical operation.
	'After research' situation 730 620 to 840	As at time T_1 it is assumed that at the end of the period of research, the limits will be $\pm$15%. There is more chance of the expected capital cost increasing than decreasing as time progresses-but no estimates have been made.
Variable Operating Cost (£/ton)	'As of now' situation 42.2 30.6 to 53.8	Major raw material c_1 --- (This figure is based on a conversion and recovery efficiency of $\sim$60% $\pm$20%) Other raw materials) Variable services) Effluent disposal) c_2--- (This figure was increased as a result of streamlining the plant. No credit for steam is included, and further raw materials are assumed to be used up in the isolation of the product.
	'After research' situation 29 28 to 30	Major raw material c_1^1 ---- (This figure is based on a conversion and recovery efficiency of 92.5% $\pm$2.5%.) Other raw materials) Variable services) Effluent disposal) c_2 --- (As for the 'as of now' situation)
Fixed Operating Cost (£k)	'As of now' situation	)No change from time T_1 for process labour and supervision
	'After research' situation	)The capital related overhead charges will be reduced in proportion)to the reduction in capital (i.e. 730/935).

Figure 4.8: Annual Costs and Market Forecasts - Project M ('After research' situation - Alternative 1)

Variable		Estimates of mode and 95% confidence interval						Assumptions.
Year		6	7	8	9	10	11	
Research (£k)		7.5 6.0 4.5	6.0 4.5 3.0	6.0 4.5 3.0	6.0 4.5 3.0	4.5 3.7 3.0	4.5 3.7 3.0	As for 'as of now' situation
Selling Expenses (£k)		0.5	0.5	0.5	0.5	0.5	0.5	Research is not expected to have a significant effect on this variable.
Other Costs (£k)		59.6 47.8 36.0	58.6 46.8 35.0	58.0 46.0 34.0	59.0 46.0 33.0	59.0 46.0 33.0	59.0 46.0 33.0	"
Market 1 (UK)	Sales Volume (Ton/yr)	357 455 553	470 580 690	589 717 846	670 780 890	745 830 915	820 880 940	It is assumed that after two years of market development, the uncertainty in sales volume will be reduced by 50%.
	Selling Price (£/ton)	36.2 45.3 54.4	→ → →	→ → →	→ → →	→ → →	→ → →	The 95% confidence interval on selling price is assumed to be reduced to ±20% of the mode value.
Market 2 (Export)	Sales Volume (Ton/yr)	124 182 241	224 332 441	349 507 666	467 645 823	647 815 983	847 975 1103	As for sales volume in the UK market.
	Selling Price (£/ton)	28.5 35.6 42.7	→ → →	→ → →	→ → →	→ → →	→ → →	As for the selling price in the UK market.

FIGURE 4.9.: THE N.P.V. OF THE PILOT PLANT

ALTERNATIVE 1 - PROJECT M

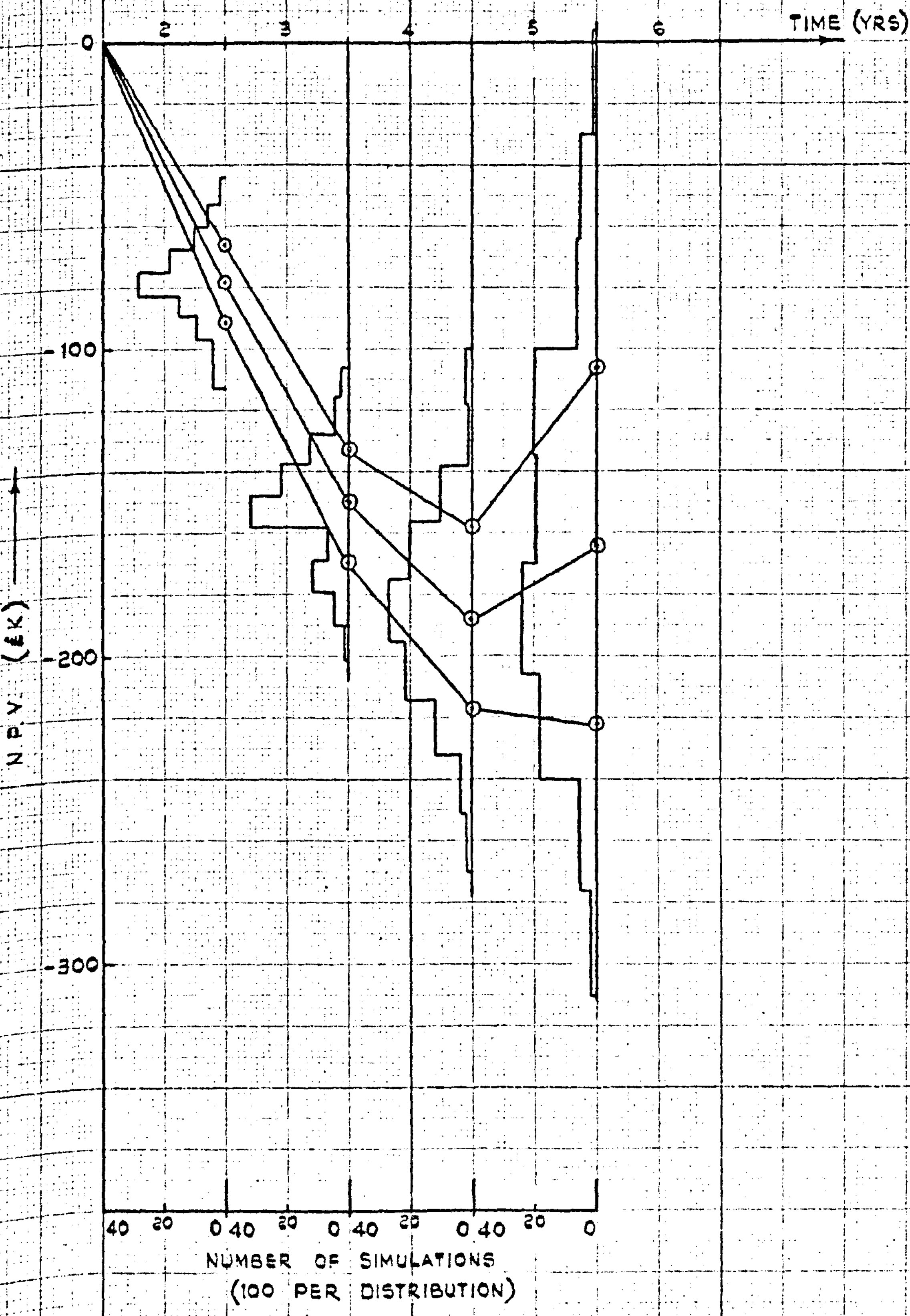


FIGURE 4.10 : THE N.P.V. OF THE FULL SCALE PLANT

ALTERNATIVE 1 - PROJECT M

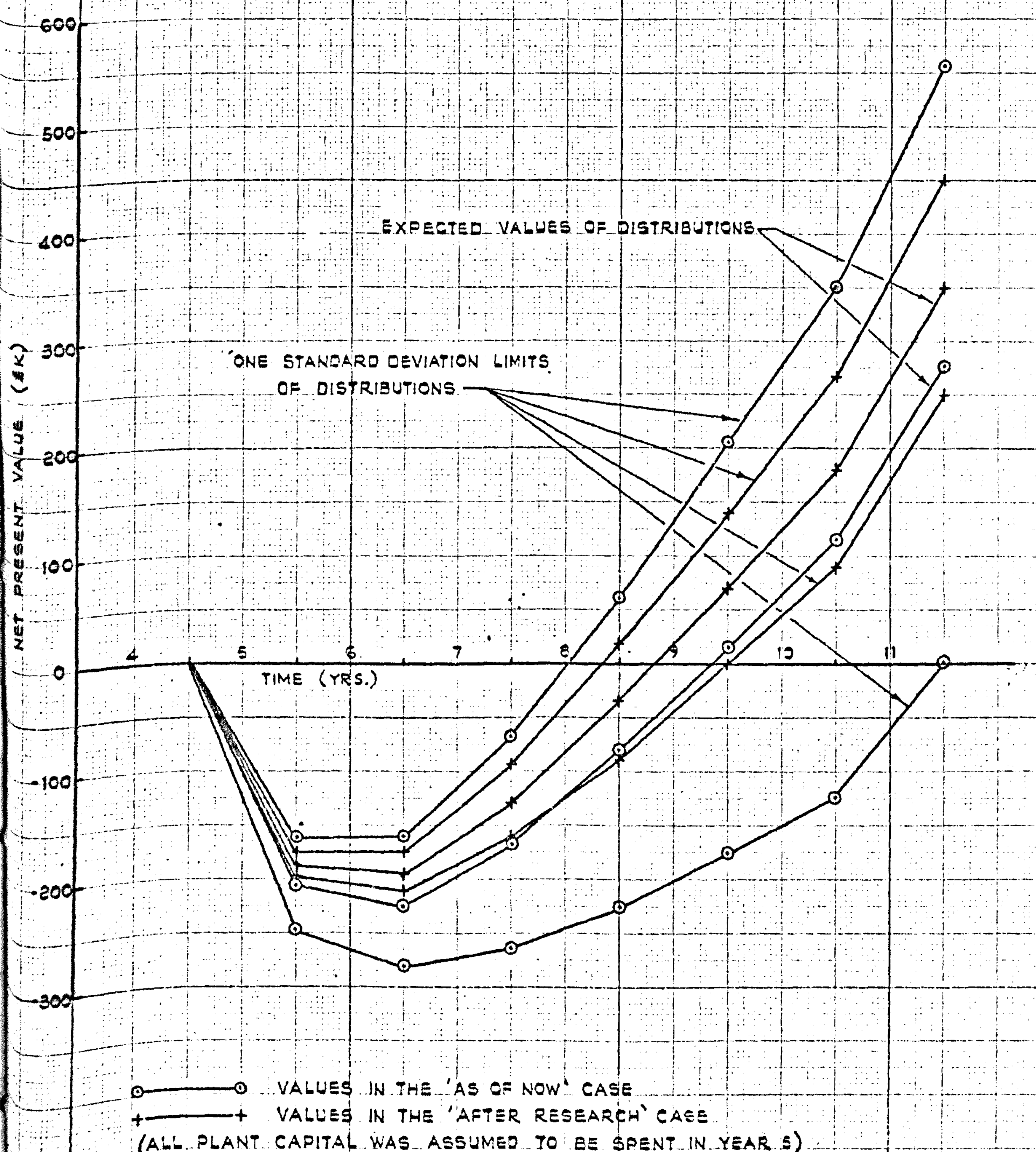


Figure 4.11 : Results of the risk analysis - Project M (Full-scale plant)
(Alternative 1 - 'as of now' situation)

Project Return.

	Year	4*	5	6	7	8	9	10	11
1	Mean net cash flow (£k)	0	-310	-29	115	193	254	294	591
2	Mean cumulative cash flow (£k)	0	-310	-339	-224	-31	223	517	1108
3	(2) discounted at 15% (£k)	0	-205	-221	-164	-81	16	113	278
4	Uncertainty of (3) (£k) (Standard deviation)	0	± 43	± 61	± 98	±144	±193	±236	±281

5+ Payback period (from the beginning of year 4) (i) 3.2 years (undiscounted).
(ii) 5.8 years (discounted).

6+ DCF rate of return : ~33%

7+ Return on capital: ~40%.

* It was assumed in the calculation that all plant capital was spent in year 5.

\+ These criteria are defined in Appendix 1.

Sensitivity Analysis.

Variable	Δr	Rank	Δu	Rank
Plant capital	28	5	13	2
Variable operating cost	37	3	3	7
Fixed operating cost	3	8	0	8
Other costs	12	7	4	6
Sales volume (UK market)	39	2	6	5
Selling price (UK market)	72	1	119	1
Sales volume (Export market)	14	6	7	4
Selling price (Export market)	37	3	13	2

Note

(i) Δr: The change in mean NPV ((3) above -yr 11) for a 10% change in variable.

(ii) Δu: The change in uncertainty ((4) above-yr 11) assuming the uncertainty surrounding the mean value of the variable is reduced to zero.

(iii) Rank orders the Δ's in terms of magnitude.

Figure 4.12: Summary of the financial returns of each alternative - Project M

No. of alternative (As in Figure 4.1)		Return of full-scale plant				Return of research and pilot plant operation			
		'As of now' situation		'After research situation		Up to decision to build full-scale plant		Up to the commission of full-scale plant	
		Return (£k)	Uncertainty (£k)	Return (£k)	Uncertainty (£k)	Return (£k)	Uncertainty (£k)	Return (£k)	Uncertainty (£k)
1	ER	278	±281	350	±100	-150	±18	-164	±58
	IR	134	±287	186	±115	-	-	-	-
2	ER	451	±279	516	± 99	-148	±20	-120	± 61
	IR	331	±286	396	±116	-	-	-	-
4	ER	451	±279	516	± 99	-98	±13	-104	±53
	IR	347	±284	412	±112	-	-	-	-
6	ER	418	±236	473	± 81	-128	±15	-101	±69
	IR	317	±246	372	±106	-	-	-	-

ER: Exclusive of expenditure on research and pilot operation up to the commission of the full-scale plant.

IR: Inclusive of expenditure on research and pilot operation up to the commission of the full-scale plant.

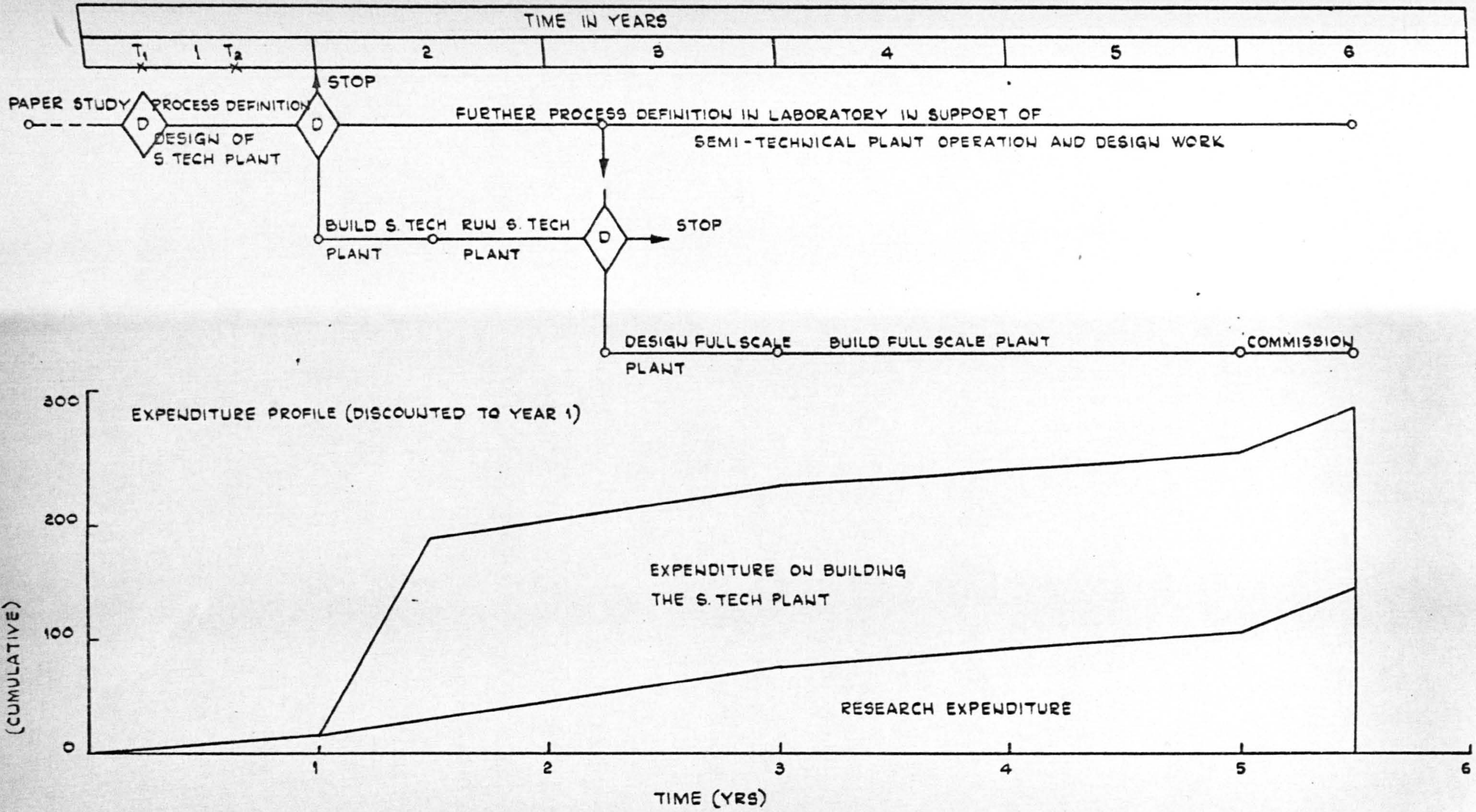


FIGURE 4.13: THE LONG TERM RESEARCH PROGRAM – PROJECT N

Figure 4.14: Viability Checklist - Project N (Route K - Time T_1)

Factors	No Problem	Minor Problem	Major Problem	Major Threat	Ignorance	Assumptions
			Raw Materials			
Security of Supply }				✓		The supply of the major raw material could become short in the long term - say 1980's - 1990's. This is likely to have repercussions on the price trends and quality of this raw material.
Price Trends }						
Hazards	✓					No problems are anticipated. The raw materials are less hazardous than those of the existing process.
Quality		✓				Route K should cope better with poorer quality raw materials than the existing process.
			Process			
Corrosion			✓			Corrosion is expected in and around the reactor. Theory suggests the problem is solvable however.
Control		✓				The control of the appropriate reaction conditions will have to be examined. No problem of control of quality of the product is expected.
Analysis		✓				One problem will be to measure accurately the yield of the reaction stage.
Reaction Stage			✓			Considerable research is needed on the reactor (which is operated at a set of conditions not, normally, met at Mond Division).
Purification Stage		✓				The system used in the present process should be applicable to the new product.
Isolation Stage		✓				There is at least one process for separating the reaction products mentioned in the patent literature.
Effluents		✓				The major effluent should present less of a problem than the effluent from the existing process.
Hazards					✓	No special hazards are anticipated at the moment. The special operating conditions could provide some surprises however.
Process Operation		✓				Should be a simple process to operate. Byproduct handling will require closer examination.
Patent Position	✓					No restrictive patents have been found for the reaction stage of the process. The isolation stage may be licenced.
Product Quality		✓				The purification stage used in the existing process should be applicable.

Figure 4.15: Plant Costs - Project N (Route K - Reactor System Q_1 - Time T_1)

Variable	Estimate of mode and 95% confidence interval	Assumptions
Capital Cost (£k)	'As of now' situation 935 701 to 1169	It is assumed that a plant of capacity 15000 ton/yr is built on a 'greenfield' site at works W. Construction to take place in years 4 and 5. Because of the new technology the cost of a second reactor as an installed spare is included. The cost is based on a tentative flowsheet derived from theoretical considerations.
	'After research' situation 935 795 to 1075	It is assumed the research programme will reduce the uncertainty surrounding the estimate of capital from $\pm$25% in the 'as of now' situation to $\pm$15%. The capital cost could well be reduced, as the plant has probably been over-designed - no forecast of the reduction has been attempted.
Variable Operating Cost (£/ton)	'As of now' situation 48.5 31.9 to 65.1	Major raw material c_1 -- (This figure is based on a conversion and recovery efficiency of 50% $\pm$20%. The high yields and recoveries reported in the literature are supposed to be unattainable without further research.) Other raw materials) Variable services) c_2 Effluent disposal)
	'After Research' situation 26.4 24.6 to 28.2	Major raw material c_1^1 --(This figure is based on a conversion and recovery efficiency of 90% $\pm$5%.) Other raw materials) Variable services) c_2^1 Effluent disposal)
Fixed Operating Cost (£k)	'As of now' situation 21.75 16.5 to 27	) Process labour and supervision
	~ 120	Maintenance and overheads - allocated on the basis of the capital and labour employed.
	'After research' situation No change from above	Research is not expected to change the costs of process labour and supervision. Allocated charges will change with changes in capital.

Figure 4.16: Viability Checklist - Project N (Route K - Time T_2)

Factors	No Problem	Minor Problem	Major Problem	Major Threat	Ignorance	Change in assumptions from Time T_1
						raw materials
Security of Supply				1,2		No change from Time T_1
Price Trends						
Hazards	1,2					
Quality		1,2				
						process
Corrosion			1,2			No change from T_1, laboratory experiments confirmed corrosion to be a major problem area. Suitable materials should be available.
Control		1,2				No change from time T_1
Analysis	2	1				Suitable methods have been devised and used. The time required (per analysis) could usefully be reduced.
Reaction Stage			1,2			The yields claimed in the patent literature have been confirmed at small scale. A number of design problems remain - these are largely dependent on the availability of a semi-tech. plant.
Purification Stage	2	1				Essentially no change from time T_1 but now considered to present 'no problem'.
Isolation Stage		1	2			System reported in Patent literature is not appropriate. Work is underway to develop a suitable system.
Effluents	2	1				Essentially no change from T_1, but now considered to present 'no problem'.
Hazards		2			1	No evidence to suggest other than routine minor problems. A special hazards investigation has yet to be made.
Process Operation	1,2					No change from time T_1.
Patent Position	1,2					No change from time T_1.
Product Quality	2	1				Essentially no change from time T_1, but now considered 'no problem'. (In conjunction with change of rating given to Purification Stage).

Figure 4.17: Plant Costs - Project N (Route K - Reactor System Q_1 - Time T_2)

Variable	Estimates of mode and 95% confidence interval	Assumptions
Capital Cost (£k)	'As of now' situation 730 550 to 910	A 15000 ton/yr plant is assumed to be built on a greenfield site at works W in years 5 and 6. The reduction in capital costs (from time T_1) is owing to (a) streamlining the process and (b) the decision not to include a second reactor system as an installed spare. No reductions in the $\pm 25\%$ limits of the confidence interval can be made before semi-technical operation.
	'After research' situation 730 620 to 840	As at time T_1 it is assumed that at the end of the period of research, the limits will be $\pm 15\%$. There is more chance of the expected capital cost increasing than decreasing as time progresses-but no estimates have been made.
Variable Operating Cost (£/ton)	'As of now' situation 42.2 30.6 to 53.8	Major raw material c_1 --- (This figure is based on a conversion and recovery efficiency of $\sim 60\% \pm 20\%$) Other raw materials, Variable services, Effluent disposal c_2 --- (This figure was increased as a result of streamlining the plant. No credit for steam is included, and further raw materials are assumed to be used up in the isolation of the product.
	'After research' situation 29 28 to 30	Major raw material c_1^1 ---- (This figure is based on a conversion and recovery efficiency of 92.5% $\pm 2.5\%$.) Other raw materials, Variable services, Effluent disposal c_2 --- (As for the 'as of now' situation)
Fixed Operating Cost (£k)	'As of now' situation	No change from time T_1 for process labour and supervision
	'After research' situation	The capital related overhead charges will be reduced in proportion to the reduction in capital (i.e. 730/935).

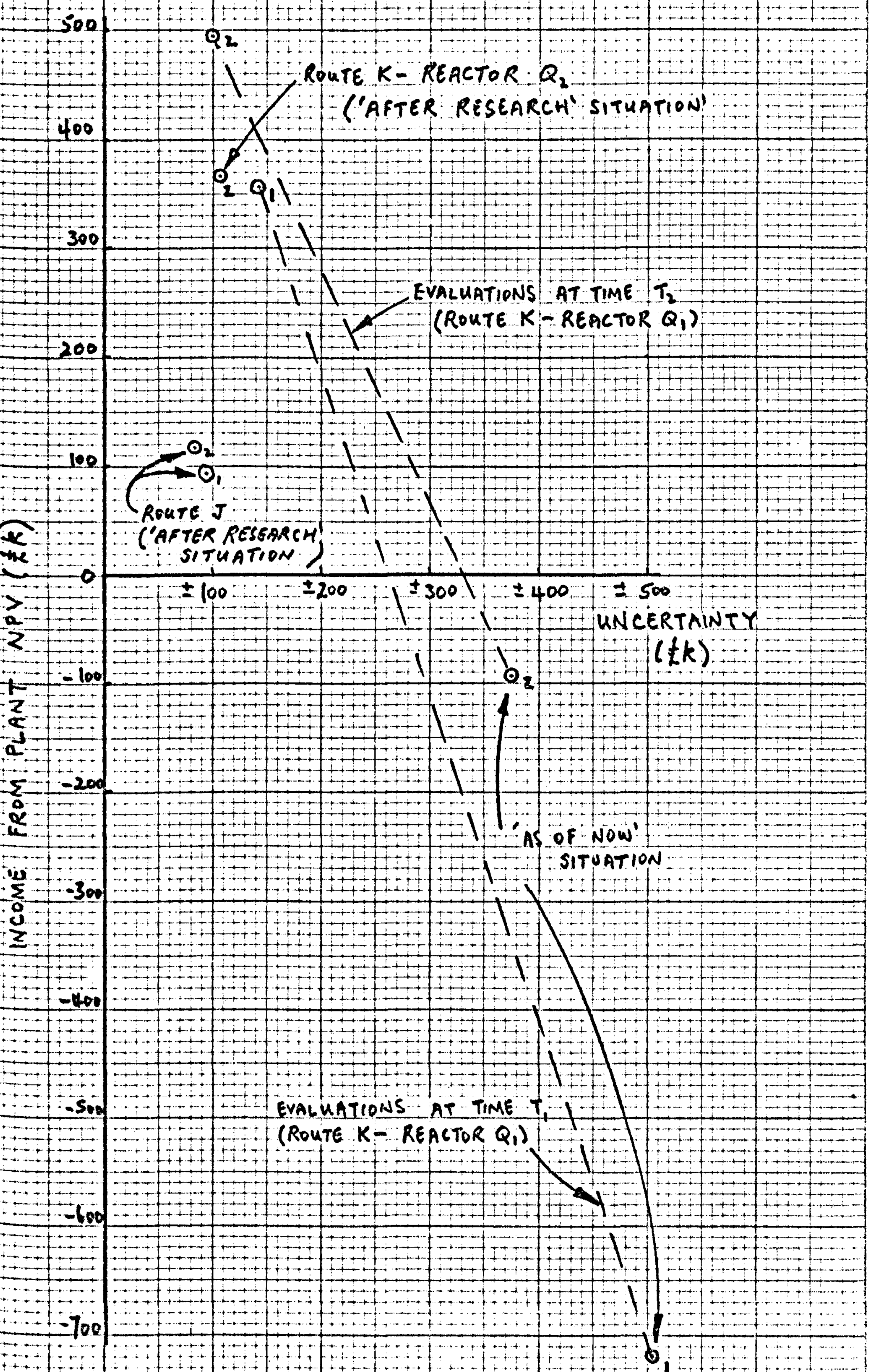


FIGURE 4.18: PROJECT N - INCOME AT TIMES T_1 AND T_2.

Chapter 5

THE FIT OF RESEARCH PROJECTS WITHIN THE LONG TERM PLAN OF THE ORGANISATION

In view of the increase in company planning activity, it was suggested in Chapter 2, (Section 2.3.4) that it was timely to consider the problem of matching research projects to the long term plan of the organisation. Much of the literature recommends that research managers concentrate their attention on the maximisation of a financial criterion. Even if it is supposed that the ultimate objective of the firm can be expressed in this manner, criteria such as NPV, DCF rate of return, and return on capital, all fall short of measuring returns in the long term. Projects give rise to products generating income far beyond the time period over which reliable forecasts of profit can be made. Furthermore, measuring the profitability of one project is not likely to include the benefits the project may bring, to related current and future projects. It may be expected, not unreasonably, that future projects may take advantage of skills, equipment and markets gained during the course of current research work.

The viability checklists of Chapters 3 and 4 were a first step away from a wholly financial evaluation. A variety of other factors, related to the wider implications of research must also be considered, particularly if it is required to assess projects against the long term plan of the firm. One class of assessments is concerned with the performance of the project with respect to the long term objectives of the organisation and its social responsibilities and constraints. Another is needed to examine the interaction of the proposed venture with the existing assets of the firm, or those embodied in future undertakings. This question is closely related to the synergy between the project and the organisation (see Appendix 5). A third set is concerned with the competitive position of the firm relative to that of competitors marketing, or likely to market, products offering a similar effect to that of the innovation.

To facilitate these assessments, three checklists were devised scanning long term objectives, synergy, and competitive position. (These lists are discussed in detail in Section 5.1). In developing the checklists the author was strongly influenced by the work of Ansoff. The reader may well recognise many descriptive terms, in the remainder of the Chapter, that appear in Ansoff's book 'Corporate Strategy' (11). This describes a useful model of dynamic adaptive planning, but maintains a strong bias towards resolving the threats and opportunities of the firm by acquisition (i.e. merger or takeover). The book has relatively little to say on the use of research and development as an instrument for the achievement of company goals. This lack greatly limits the applicability of the Ansoff model to the research situation, but with the recasting of some classifications, it becomes a useful guide and reference standard.

It is suggested that before turning to the next section, readers unfamiliar with Ansoff's book should refer to Appendix 5. This defines terms and summarizes the main points.

5.1 The Checklists.

The three checklists which were developed are presented in completed form in Figures 5.1 to 5.5. It was assumed that the factors covered in the lists would be assessed at the evaluation step of the cycle of decision and control (Figure 3.1). Furthermore, it was assumed that at the 'decision' and 'problem identification' steps of the cycle, reference would be made to performance with respect to the long term objectives, synergy, and competitive position checklists, as well as to the viability checklist and financial evaluation of Chapters 3 and 4.

Scores or ratings were used to give an indication of the level of achievement of the project with respect to each factor. The practice of the viability checklist was followed by requiring the assumptions supporting the factor scores to be recorded in the adjacent column.

5.1.1 The long term objectives checklist (Figures 5.1 and 5.2).

The long term objectives of the organisation were considered under the main headings of long term growth, stability and flexibility. A fourth heading concerned with the responsibilities and constraints the project must satisfy was also included. The latter may be imposed by the firm, or by society in general. For example any firm that values its reputation will be particularly concerned with the problems of environmental pollution, and will be extremely reluctant to introduce products that threaten environmental conservation. Similarly, account will be taken of the standing of the venture relative to constraints imposed by society in the form of legislation. With respect to the latter it is important to try and assess the possible effects of future, as well as existing legislation. Each of the main objectives was sub-divided into a number of relevant factors. This step corresponded closely to Ansoff's introduction of 'proxy objectives' (see Appendix 5). The stability objective was considered by assessing the effect of the project on the cyclical patterns, or in-balances, which might exist, or might arise, in the firm's raw material supply, production, or sales. The flexibility objective is concerned with the ability of the firm to react swiftly to the unexpected, whether it be threat or opportunity. This was assessed by first considering the effect of the project on the store of R & D skills, technologies and customer contacts. Secondly, the ratios of working capital, annual sales income, and annual profit, to total capital (working capital + fixed capital) were estimated and compared with the average figures for the firm as a whole.

(In the author's case this was the Mond Division of ICI). Where the factors were not otherwise quantifiable in the way that the ratios above were, then the factors were rated on the scale -2, -1, 0, 1, 2, according to whether the contribution of the project, with respect to the factors, was judged to be:
poor, fair, average, good, or excellent.

5.1.2 The synergy checklist (Figures 5.3 and 5.4).

The factors in the synergy checklist were sub-divided according to the expertise of staff, and according to the various systems, special equipment and plant available. Some factors related to the customer were also included, in recognition of the fact that synergy is also possible between a product and, for example, a customer's product line, or processing equipment.

The synergy rating or score indicates that in addition to the return of the project, which might have been evaluated in terms of a financial criterion, there are further interactions that should also be given consideration. Four ratings were used to classify the synergy between the project and the firm, or potential customers:

(1) A score on the scale -2, -1, 0, 1, 2 according to whether the interaction is strong or weak; negative, neutral or positive. For example if, because of existing channels, the organisation could distribute the product more cheaply than might be expected, then this factor could constitute a positive synergy. (A score of 1 or 2 would be assigned, depending on the extent of the interaction.)

(2) A label C or P according to whether the interaction was 'certain' or 'possible'. Suppose a new product is launched, an example of a 'certain' synergy would be the existence of a pilot plant that could be readily converted to meet the requirements of the product. An example of a 'possible' synergy could be the boost in sales of an existing member of the product line that might also occur.

(3) A label I or E depending on whether the interaction had been 'included' or 'excluded' from the financial evaluation. This index was to ensure against double counting. For example, if as in (2) above, a pilot plant was available at a reduced cost, then normally the project would have been charged a reduced amount in the financial evaluation.

(4) A label TP, J or TC depending on whether the contribution was 'to the project from the company', 'joint' or 'to the company from the project'.

When synergistic links were especially complex, it was found helpful to follow Ansoff's scheme of distinguishing between 'investment', 'operating' and 'timing' contributions. (These terms are defined in Appendix 5; Figures 5.6 and 5.7 provide examples).

The analysis of synergy was felt to be incomplete without a consideration of the extent to which synergy would also be available to competitors wishing to satisfy a similar market need. The right hand side of the checklist was therefore concerned with an assessment of a rival's synergy. Clearly the quality of the relevant information will not normally be high. The factors of the checklist were therefore rated: $>$, $=$, $<$ according to whether Mond Division's opportunity for synergy was considered to be stronger, comparable, or weaker than the competitors. Following the previously established convention, the appropriate assumptions were also recorded.

5.1.3 The competitive position checklist (Figure 5.5).

The factors of this checklist were collected under two main headings focusing attention on the competitive position of the product and the firm, relative to similar products and their manufacturers.

The former was analysed by reference to a set of factors related to the rate of diffusion, or acceptance, of the innovation embodied in the new product. The headings are those proposed by Rogers (68) and require elaboration:

(1) Relative advantage is the degree to which an innovation is superior to the ideas, or methods, or goods, that it supersedes.

(2) Compatibility is the degree to which an innovation is consistent

with existing values and past experiences, or with the presently existing operations, of the adopters.

(3) Complexity is the degree to which an innovation is difficult to understand and use.

(4) Divisibility is the degree to which an innovation may be tried on a limited scale.

(5) Communicability is the degree to which the nature of an innovation may be transmitted or described to others.

The competitive position of the firm was assessed by consideration of a more traditional set of factors covering areas where advantage might be achieved. These included the cost of entry, the patent position and the market share that might be gained.

The procedure was first to identify the most important competitive products and their manufacturers. The checklist factors were then used as a basis for assessing the attributes of the firm and the product against each competitor and their product. Once again a scale of -2, -1, 0, 1, 2 was used to give an approximate measure of the competitive position of the firm.

5.2 Implementation of the System.

The system was tested on several of Mond Division's new product projects. These were chosen because new products are generally, by their nature, more interesting from a strategic point of view, than existing products. The completed set of forms in Figures 5.1 to 5.7 present the analysis of one project. Figures 5.6 and 5.7 are not mandatory, and are a supplement making a more thorough examination of some aspects of synergy. For convenience all the figures are collected together at the end of the Chapter. As in other parts of this thesis, product names have been suppressed and comments have been suitably adapted, to preserve Company security. The general style of comment in the 'assumptions' column of checklists has been retained as far as possible.

5.2.1 Some Practical Results: Product A.

Exploratory Research in area of chemistry AC had been underway for some years. The project leading to product A was started when some practical applications of this research had been recognised. In terms of the network Figure 2.2 (Chapter 2) a process had been discovered, defined on a laboratory scale, and a pilot plant was about to be commissioned. The latest economic evaluation indicated a most promising future for the project. Product A was an additive and, at the time of assessment, one major and several minor applications had been identified. Moreover the capital required for pilot scale production was small, as use could be made of existing plant.

It was felt that the strongest competition would come from two firms - X_1 and X_2. The first was in the process of test marketing a product almost identical to product A. The second had a very strong background in area of chemistry AC, and for some years had marketed a product with similar, and perhaps slightly superior properties to those of product A. However X_2's product was significantly more expensive than Mond Division's and required the customer to make a greater number of modifications to his equipment.

The financial calculations are not reported in this Chapter, the analysis is restricted to the three checklists introduced in the previous section.

5.2.2 Long Term Objectives: Figures 5.1 and 5.2.

It is clear that the project provided Mond Division with a number of opportunities for realising long term objectives. Not surprisingly, the project provided growth in sales and profit turnover. Also by establishing an interest in another segment of an existing market area, a well defined product line was extended. The Division's flexibility was also improved. A production base in a new area of technology was established and new customers in overseas markets were expected to be gained. It also appeared that the turnover of capital with respect to both annual sales income and profits, should eventually be well in excess of the average figures for Mond Division. On the other hand, because of the relatively high selling price, and low capital cost (by the Division's standards) the ratio: working capital/ total capital was well above the average for the Division as a whole.

It was evident that the project also satisfied the various responsibilities and constraints imposed by both the Company and Society. In the event of successful marketing there was good reason to expect that the public image of the Company and the sales of other members of the product-line would be enhanced. Legislation also imposed no threat, indeed it was considered that the project could even benefit from the introduction of tighter legislation.

5.2.3 Synergy: Figures 5.3, 5.4, 5.6 and 5.7.

The basic analysis, Figures 5.3 and 5.4 showed that there are several areas where synergy was strong. For example, owing to skills in research, skills in selling and promotion, the existence of pilot plant equipment, the existence of a well defined product line. To illustrate the method of classifying the contributions, the interactions between the project and research are described in detail.

The synergy arose firstly, because of a long standing research interest in area of chemistry AC and other fields related to the chemistry of product A. The research effort, and the time required to develop A, were therefore less than might have been expected because work began from a substantial base of knowledge. This interaction was classed: 1 C I TP because synergy was considered to be:

(1) Strong.

(2) Certain: the base of knowledge was a fact, and had been used.

(3) Included: the actual costs of research had been included in the financial evaluation of the project.

(4) To the project from the Company.

The second interaction arose because area of chemistry AC held promise for a number of other possible future ventures. These in turn would benefit from knowledge gained prior to, and during research on product A. This interaction was classed 1 P E J because synergy was considered to be:

(1) Positive but not necessarily strong.

(2) Possible: the future projects had yet to be clearly defined.

(3) Excluded: no attempt to estimate this interaction was included in the financial evaluation of product A.

(4) Jointly dependent on the Company and the research leading to Product A.

More detailed examination of the synergy between product A and 'raw materials' and 'existing product lines' were made because these interactions were more complex. The analysis was conducted along the lines suggested by Ansoff (see Appendix 5) with synergy assessed according to whether it is of the types:

(i) Investment, timing, or operating.

(ii) To the project from the Company, to the Company from the project, or joint.

The results are presented in Figures 5.6 and 5.7 and show that, within the areas of 'raw materials' and 'existing product lines', several distinct synergies emerged. They also provided some examples of contributions 'from the project to the company'. Thus with respect to the existing product line, one effect of introducing product A was expected to be an increase in sales of the existing members of the line. This clearly was a synergy 'from the project to the company'.

Owing to the lack of necessary data, the assessment of competitor's synergy (X_1 and X_2 in this case) was made on a somewhat rougher basis than the assessment of synergy between the project and the parent organisation. Some factors were considered in groups, for example:

(i) Skills in research, engineering and process management, and

(ii) the availability of a distribution network and technical service facilities, were considered together as single factors.

It seems likely that the synergy between Mond Division and product A was stronger than that available to firm X_1 and their product. This conclusion stems largely from the existence in Mond Division of a well defined product line, which A neatly extended.

On the other hand it was felt that firm X_2 could expect stronger synergy in those areas closely related to area of chemistry AC: research, engineering and production. But once again Mond Division's existing product line seemed likely to give some advantage in the marketing area. It also appeared that the customer would experience greater synergy by adopting Mond's product in preference to X_2's.

5.2.4 Competitive Advantage: Figure 5.5.

The competitive position of product A was shown to compare favourably with X_1's product. It seemed likely (from patent information) that Mond Division's product would offer the customer a higher relative advantage than X_1's. Furthermore, because of the existence of a product line, it appeared that Mond Division would have competitive advantage with respect to both specialized support (staff and equipment) and marketing organisation. The main disadvantage lay in the patent position. A broad patent claim in the USA could seriously jeopardize the Division's position in this market. This threat was under examination at the time of assessment.

Relative to X_2's product, product A was shown to present a more balanced competitive position. The relative advantage of product A was considered to be much superior to that of X_2's product. The current selling price of the latter was several times that expected of product A. The customer was also likely to gain by adopting product A, as this was generally more compatible with existing equipment. These advantages were off-set, however, by the established position which X_2's product held in the market. It had been in production for some years and was well known. In addition, a greater proportion of the funds necessary for R & D and production had been committed by X_2 and thus their risk of continuing would be correspondingly less.

5.3 A comparison of Product A with two other new products.

Two other Mond Division new products projects were evaluated concurrently with product A. It is of interest to compare the assessments of long term objectives, synergy and competitive position. The aim is to draw out some of the more interesting points that emerged and to illustrate how the system highlights the differences between projects. It is not proposed to make a detailed comparison, or to present all the results obtained. For simplicity the other two products are labelled G and H.

Product G had two main uses: as an additive (in this respect G was similar to A), and as a replacement for one of Mond Division's traditional products (more specialized properties were on offer, in return for a higher price). On the other hand product H aimed to satisfy one particular market or need.

The different types of growth provided by the three projects are summed up in the diagram below which is based on Ansoff's growth vector (see Appendix 5).

Product / Market	Old	Similar	New
Old			
Similar		G	A
New			H

The diagram shows that though all three research projects were classified as 'new product' projects, the type of growth offered by each was rather different. Product G was expected to produce only a slight shift away from the existing business, whilst product H promised a significant diversification.

5.3.1 Long Term Objectives.

It was found that the performances of all three products were expected to be similar with respect to the achievement of long term objectives. Not surprisingly each gave Mond Division prospects for growth and an increase in flexibility. Of course differences emerged, but these were mainly of degree, for example:

(1) Product A showed a significantly higher profit, for a sales turnover similar to those of products G and H.

(2) Products A and H promised a greater boost in the public image of the company than project G - because of their greater sophistication and the nature of the effects produced.

(3) Though H was a new product satisfying a new market need, the potential customers were in general not new (because of an existing product line).

Project H therefore failed to enhance the flexibility of the division in this respect.

Only product G offered a possible increase in the stability of the Division. The reason for this was that one of the uses of G was as a possible replacement for a traditional product of the Division. There was some evidence to suggest that other competitive products, similar to G, could capture sales of the traditional product. If this occurred then clearly Mond Division could hope to reduce their losses by additional sales of G.

5.3.2 Synergy.

It was clear that all three projects provided a number of strong synergistic links with the Division. Some of these were common to each of the projects. For example: in research, in the availability of pilot plant, in the existence of distribution channels and product lines.

Product A (Figures 5.3 and 5.4) showed the strongest links - no negative interactions were recorded for this project. Negative synergy was evident with respect to products G and H however. The Division's sales representatives were highly experienced in selling large lots of products similar to G, but initially ability to sell in much smaller lots was required. Mond Division's engineering skills, in large scale single stage continuous processes, might not be appropriate to the need of product H. In the first instance this was for a small, cheap, multistage batch process.

The comparison of Mond Division's synergy with that of potential competitors showed that, in general, the synergy available to Mond Division was well matched by that available to competitors. This was because, in the projects considered, the main competition was provided by major international companies with resources and expertise comparable to those of Mond Division. Most of the comparisons were similar therefore to that between Mond and firm X_2 (Figures 5.3 and 5.4), in which the strengths of Mond Division with respect to some of the factors tended to be balanced by the strengths of X_2 with respect to other of the factors. The comparison most favourable to Mond Division was that with firm X_1. On technical grounds it appeared that the Division's synergy was comparable to X_1's but because of an existing product line Mond Division seemed likely to have access to stronger synergy with those factors concerned with the market.

It is interesting to note that synergy played an important part in the decision to transfer project H to another Division of ICI that had stronger links between the project and research expertise, engineering expertise, and production facilities.

5.3.3 Competitive Position.

The first conclusion on comparing the relevant checklists was that a strong competitive position is difficult to achieve. The most likely situation is one in which the project is characterized by both competitive advantages and competitive disadvantages. This simply reflects the conclusions concerning the synergy of competitors (see the above section).

The competitive positions of projects A and G were similar to the extent that the new products were intended to replace similar products already on the market. (In this context 'similar' includes both the form and the effect of the products.) The main selling points in both cases were either a slight difference of effect, or a lower selling price. Product H on the other hand was radically new and provided a novel method of satisfying an established market need. These differences were reflected by the entries against the factors concerned with the competitive position of the product: relative advantage, compatability, complexity, divisibility and communicability. Only relative advantage, and to a certain extent compatibility, provided grounds for differentiating between products A and G and competitor's products. Product H, on the other hand, could be usefully compared with its main rival with respect to all five of the above mentioned factors.

A point common to all three products was that 'cost of entry' provided Mond Division with no significant competitive advantages. The reason once again was because competition was provided by large corporations. In each case however, the costs were such as to deter small companies and backyard manufacturers from entering the market.

It would appear from products A, G and H that the simplest means of achieving a strong competitive position is through a sound patent position. Providing sales can be built up rapidly during the period of protection, the advantages of large scale operation can be gained before competitors may enter. For this reason a score of -2 was entered against the market share factor of product G. Rivals were already well established in the business area and had the advantage of high volumes of production. Of the products considered, only H enjoyed a strong patent position. However, this was off-set by some uncertainty surrounding the relative advantage of the product, and the difficulty (or 'complexity' - see Section 5.1.3) of explaining the philosophy of the effect to customers.

5.4 Discussion.

The analysis of a project and the processing of the data usually took about one working week, spread over a longer period of time. The main activities were:

(1) Reading up the background to the project.

(2) Explaining the objectives and form of the system, to those responsible for providing the information.

(3) Eliciting the necessary information.

(4) Completing the forms.

(5) Agreeing the statements with those providing information.

On most occasions it was necessary to repeat steps (3) to (5) at least once before complete agreement was reached.

It was found to be essential for the author to spend time explaining the checklists to persons providing the information: project managers, research scientists and those concerned with marketing. This was because some were not familiar with the terms of the analysis - for example flexibility, synergy, competitive advantage. There were also problems of interpretation, as many of the factors are only broadly defined, and it was necessary to ensure uniform conventions. Thus, for example, 'growth of sales' was expressed in terms of the expected turnover and profits at the end of a period rather than in percentage terms; the 'relative advantage' factor of the competitive position checklist required equal emphasis to be given to both the benefits and costs of a product.

When terms and their interpretation had been made clear, it was not difficult to obtain the information required, and to apply the simple scoring system (-2, -1, 0, 1, 2). The original intention was to use the cruder (-, 0, +) scoring system, but this was found to be limiting; even though information was often qualitative, it was still possible and useful to distinguish between 'minor' and 'major' effects. A notable point was the absence of many negative scores. (Figures 5.1 to 5.7 bear this statement out.) One reason could be that the projects considered had each passed several stages of screening and thus were not subject to any obviously decisive disadvantages or weaknesses. On the other hand, there might have been a tendency for assessors to avoid admitting to a project performance worse than neutral, in order to preserve good relations with other members of the project team, or other departments, perhaps.

Another 'scoring' problem arose when factors could be assessed from more than one point of view. An example was provided by the synergy between project A and research expertise (Figure 5.4). The convention was to adopt a single rating of factors but, when this could confuse or mislead multiple entries were allowed. (For example, if from one point of view a factor could be rated 2, and from another -2, it would be misleading to give the factor a rating of zero. Figures 5.6 and 5.7 provide other examples of multiple entries against factors.

The output of the system - the completed checklists, was generally well received and found to be useful by the managers of the projects concerned. It was also agreed that the approach offered some advantages over the periodic progress report in which comparable information is normally provided. These are:

(1) It ensures that a number of relevant points related to the wider implications of research receive consideration (assuming that after a period, efficient checklists are established). If discussion of one aspect of the project is omitted in progress reports, it is not absolutely clear whether it has been deliberately ignored, because it is unimportant, or whether it has been forgotten.

(2) The manner of presentation is very concise, this should enable those not intimately concerned with the project to appreciate more readily the strategic background. Also comparison of projects will be simplified (either of different projects, or of the same project at different times), as the approach to each is uniform. This point was borne out by the comparison of projects A, G and H made by the author.

At present Mond Division's senior management does not require that projects meet a set of long term objectives and strategy requirements in the manner envisaged by Ansoff in his book 'Corporate Strategy' (see Appendix 5 for an example given by Ansoff). However this situation may well change and if it does the methods described in this Chapter will have contributed by demonstrating the feasibility of the long range look. On the other hand the approach shared the criticisms of the viability checklist of Chapter 4 - that the obvious was often stated and that comments were sometimes too brief to be helpful. The answers to these criticisms given in Section 4.7 apply equally well to this Chapter. Once again the checklists are seen as a complement to, rather than as a replacement for existing forms of reporting, which provide the freedom and space to give detailed attention to the sensitive issues.

An attempt was made to extend the results of the checklist analysis along the lines suggested by Ansoff, and a simple scoring model was devised that took account of the achievement of objectives and the strategic fit of the project. The purpose of the model was to enable an order of merit to be established for purposes of project selection. However it was never taken beyond the experimental stage. Some managers were asked for their views on the structure of the model and the consensus opinion was, that they would prefer to be given the relevant information and then to order projects according to their judgment, rather than to build their judgment into a model and to order according to a project score. It is firmly held that this preferred approach of the managers is the most appropriate for project evaluation in the chemical industry.

Figure 5.1: Long Term Objectives (Product A)

Long Term Objectives	Factors	Rating	Assumptions
Growth	Product Sales	2	Sales should increase to about s ton/yr by yr Y, when turnover should reach £T, and profit £P. Growth of turnover and profit is well above average.
	Product Line	2	Two existing products in the general area are B and C; A is a good complement to both. The turnover and profits of B and C by yr Y, are $£T_1$, $£P_1$, and $£T_2$, $£P_2$. The business of the line is thus greatly increased.
	Market Share	1	The aim is to achieve a p% share of the world market (for products of type A). At the moment the market is shared between two companies X_1 and X_2.
Stability	Raw Material Requirements	0	The stability of neither Mond Division, nor ICI, is significantly affected by product A. (There are no reductions or increases in cyclical patterns, or inbalances).
	Plant Utilisation	0	
	Sales	0	
Maintenance of Responsibilities	The Company	2	The markets for the product are such that the company image should be enhanced. (The product could help to save life). There is also some novelty in the technology.
	Workers	0	The principal raw material requires careful handling and there is a slight effluent problem. It is considered that solutions to these problems have been found.
	The Community	1	As far as can be seen, legislation poses no threat to the project. In fact, more stringent regulations could improve prospects.

Figure 5.2: Long Term Objectives (Product A) continued

Long Term Objectives	Factors	Rating	Assumptions
Flexibility	Research Experience	1	Product A will ensure a continued research interest in the promising area of chemistry AC.
	New Technology	2	With product A a production base in a new area will be established. It is thought that a number of other products, in the field AC may be co-produced on the pilot plant.
	New Customers	1	Few new customers will be gained in the UK (due to the existing product line). It is hoped to secure new customers in export markets (US, EEC, Japan, South Africa).
	The Negotiating Position	1	A strong position in field AC had been established. In present circumstances it is unlikely that Mond would want to sell information.
	$\frac{\text{Working Capital}}{\text{Total Capital}}$	R_1	This ratio (R_1) in year Y, is well above the average (A_1) for the Division as a whole. (Because of the low fixed capital and relatively high cost of the product.
	$\frac{\text{Sales income}}{\text{Total Capital}}$	R_2	This ratio (R_2) in year Y, is well above the average (A_2) for the Division as a whole.
	$\frac{\text{Profit}}{\text{Total Capital}}$	R_3	This ratio (R_3) in year Y, is well above the average (A_3) for the Division as a whole.

Figure 5.3: Synergy - Expertise of Personnel (Product A)

Factors	Synergy Contribution of Project					Firm's Synergy relative to Competitors			
						Competitor X_1		Competitor X_2	
	Rating				Assumptions	Rating	Assumptions	Rating	Assumptions
General Management	0				No specific strengths or weaknesses	=	Comparable to Mond	=	Comparable to Mond
Research (i)	2	C	I	TP	There is an active research team working in the area AC which has several years experience. Mond also has research experience in the other related areas of chemistry.	=	Firm X_1 have been active in area of chemistry AC for approximately the same period as Mond.	<	Area of chemistry AC has been a particular strength of company X_2 for a number of years. Several related products satisfying a variety of effects are already in production.
(ii)	1	P	E	J	The research experience gained could benefit future projects in the area AC				
Engineering	1	C	I	TP	Can exploit the expertise of another Division of ICI to help with the first stage of the process.				
Process Management	0				No specific strengths or				
Process Operation	0				weaknesses				
Selling	2	C	I	TP	A team is already in existance, responsible for selling an existing line of products. Many of the contacts with potential customers and with those responsible for authorisation, have therefore been established.	>	Personnel in X_1 probably have less experience in selling the effect concerned than personnel in Mond	=	Personnel in X_2 already sell a product with effect similar to that of product A.
Promotion	2	C	I	TP	Have gained much experience of promotion by mounting displays concerned with sales of other members of the product line. Mond has, on its staff, experts in demonstrating the application of the product.				

Figure 5.4: Synergy – Equipment, Systems, Customers (Product A)

	Factors	Synergy Contribution of Project					Firm's Synergy Relative to Competitors			
							Competitor X_1		Competitor X_2	
		Rating				Assumptions	Rating	Assumptions	Rating	Assumptions
Research	Laboratory Equipment	1	C	I	TP	Mond Division has already specialist laboratory equipment required for further research work.	=	X_1 are a large international chemical company and as such will have access to a wide range of equipment, plant and raw materials	<	X_2 have marketed products related to area of chemistry AC for many years. They are likely therefore to have greater access to suitable laboratory equipment and production units than Mond.
	Semi-technical Equipment	1	C	I	TP	Another ICI Division have redundant equipment that may be used in the first stage of the process.				
Works	Plant	0				No specific strengths or weaknesses				
	Services	0								
	Raw Materials					Analysed in greater detail on a separate sheet. (See Figure 5.6).				
Marketing	Related Product Lines					Analysed in greater detail on a separate sheet. (See Figure 5.7).	>	Mond's product line is more complete than X_1's	>	Mond's product line is more complete than X_2's.
	Distribution Network	1	C	I	TP	A network is already in existance for distribution of the other members of the product line.	>	Mond probably have wider experience of these areas because of the existing product line.	=	Comparable to Mond.
	Technical Service	1	P	E	TP	This project should benefit from experience gained and current work concerned with the existing product line.				
	Chain of Customers	1	P	E	TP	The eventual customers in the UK are well known to Mond Division.	=	Mond's advantage in the UK is balanced by X_1's abroad.	=	Mond's advantage in the UK is balanced by X'_2s abroad.
	Customer's Equipment	1	P	E	TP	Product A should have no detrimental effect on the customers process or product. It is very innocuous and only a small amount is required to enhance considerably the effect of the customer's product	=	X_1's product is very similar both in form and effect to Mond's.	>	The adoption of X_2's product requires the customer to make more modifications to his existing equipment than Mond's
	Customer's Product									

Figure 5.5: Competitive Position (Product A)

Factors			Competitive Position of Firm Relative to X_1		Competitive Position of Firm Relative to X_2	
			Rating	Assumptions	Rating	Assumptions
Competitive Position of Product	Relative Advantage		1	Mond's product offers a comparable effect to X_1's. There is evidence to suggest however, that Mond should be able to sell at a lower price.	2	The effect of Mond's product is almost comparable to X_2's. The estimated selling price of Mond's product is substantially lower however.
	Compatability		0	The positions of Product A and X_1's product are comparable with respect to these factors. (The products are very similar in both form and effect).	1	Mond's product requires customers to make fewer modifications to their equipment than X_2's.
	Complexity		0		0	The positions of Product A and X_2's product are comparable with respect to these factors.
	Divisibility		0		0	
	Communicability		0		0	
Competitive Position of Firm	Cost of Entry	Capital	0	The total investment is not exceptional by present day standards. Both Mond and X_1 are in a similar stage of product development.	-1	X_2 have spent a greater proportion of the investment needed to establish their position in the market than has Mond.
		Research	0		-1	
		Specialized Support	1	Mond probably have access to greater experience and more equipment than X_1 (because of their existing product line).	0	The positions of Mond and X_2 are comparable with respect to this factor.
	Raw Material Supply		0	Both Mond and X_1 have control of their raw material supply. (This factor could deter smaller companies from entering).	0	Both Mond and X_2 have control over their raw material supply.
	Patent Position		-1	A broad patent claim in the USA by X_1 could render Mond's position in this market unfavourable.	0	The positions of Mond and X_2 are comparable with respect to this factor.
	Market Share		0	Mond and X_1 are both starting from similar positions.	-1	X_2 are already well established but have not achieved a dominant position.
	Marketing Organisation		1	Mond should have an advantage over X_1 because of the existance of a related product line.	0	X_2's experience in marketing their product is balanced by Mond's more general experience of the area (through the existing product line).

Figure 5.6: Synergy – Raw Materials (Product A)

Contribution \ Synergy Type	Investment	Timing	Operating
To Project from Company	2 C I TP The principal raw material is not available on the open market ICI have the only production unit in the UK and have spare capacity. To use Mond Division's technology, other UK producers would first have to establish capacity for the above raw material. This would add considerably to the cost and time for development.		1 C I TP The scale of production of the principal raw material is far in excess of the requirements of Product A. Product A thus has some of the advantages of large scale production. All the other raw materials are under ICI control.
To Company from Project			1 P E TC As a result of product A the plant producing the principal raw material will operate at a higher capacity and thus greater efficiency. (A very small effect initially).
Joint contribution to Project and Company	1 P E J The plant producing A may be readily adapted to produce small quantities of raw materials for other new products in area AC. The development costs of these products will therefore be reduced.		

Figure 5.7: Synergy – Related Product Line (Product A)

Contribution \ Synergy Type	Investment	Timing	Operating
To Project from Company	2 C I TP		
	Experience gained with the two other members of the product line (Band C) has established expertise in research, technical service and marketing. Links have been made with those responsible for authorisation to use the product, with the intermediate manufacturers and the eventual customers. Without these advantages, which have been freely available, the development and later stages of product A would have been much more costly and time consuming.		
To Company from Project			1 P E TC
			Product A is an excellent complement to one of the other members of the product line, there is good reason to believe that availability of A will help boost the sales of this other product.
Joint Contribution to Project and Company	1 P E J		
	The product line may be extended still further by the introduction of another product related to product A. The product line and product A together will expedite the introduction of product Q.		

Chapter 6

CONCLUSION

The system of project evaluation and control that has emerged as a result of the research described has linked a variety of techniques that together form a tool for project evaluation and control. These include:

(1) Tree networks that display some of the different future situations that may arise and that identify alternative policies for project development. Tree networks can be combined with a time base that enable activities to be scheduled against a time scale.

(2) Viability checklists that call for attention to a variety of factors important to the appraisal of the emerging system.

(3) Forms for recording the data input to the financial calculations: the mode values and the accompanying confidence intervals of cash costs and benefits.

(4) Methods for calculating the project return, for analysing uncertainty, and for presenting the output of the financial analysis in terms of various investment criteria and sensitivity analyses.

(5) Procedures for monitoring the progress of the project over time that contribute to project control.

(6) Checklists that direct attention towards the longer term objectives of the project and that draw attention to the position of the project within the overall strategy of the Company and relative to external competition.

An important aspect of those parts of the system presenting the basic data (i.e. the forms(3) and checklists (2) and (6)), was the provision for explicit statement of the assumptions underlying the estimates and assigned values. None of the above procedures is intrinsically new. The novelty lies in the linking of the techniques to form a unified and dynamic system for the evaluation and control of projects, in their adaption to meet operational requirements, and in their testing in an active industrial environment. The latter points are most important, and indeed were fundamental to the programme of research. Much of the published work gives emphasis to the formulation of new methodology and is understandingly light on practical testing in the field. The methods and procedures developed in this research had the benefit of regular working contact with managers and were repeatedly modified in the light of their comments. It is thus not unreasonable to claim that, the methods are free from the most common criticisms of new management techniques: that they are too academic, that they solve the wrong problem, or that the model is unrealistic. It is believed that the general principles of the system developed, should be more widely applicable and help improve the quality of R & D decision taking. It cannot be proved of course that the adoption of the system will lead to better decisions, because it is not normally feasible to conduct a 'control' experiment enabling decisions employing the new system to be compared with those employing the old. However, it is expected that application of the system would lead to improvements by taking account of the difficulties and shortcomings of current methods described in Chapter 2, and by providing project managers with a more comprehensive and consistent basis from which to take decisions. Tests of the systems for the evaluation and control of projects considered in detail in Chapters 4 and 5 demonstrated its utility and acceptability in practical R & D management terms.

A view expressed by a Mond Division Deputy Chairman was that while, in the last resort, success depends on the soundness of the judgment of managers - the procedures described in this thesis provided a very good basis for informing judgment, without themselves introducing bias or prejudice and for ensuring that the 'obvious' was not overlooked. Furthermore, when senior management know that such procedures have been applied, much of the need for probing into detail vanishes. This enables the dialogue to focus on patterns of strategy rather than details of tactics.

6.1 Some Future Developments.

The system that had been described could be made more effective by refining and possibly simplifying some of the procedures used in the analysis. For example, if the checklists were to be used on a routine basis, keys defining the frames of reference of each of the checklist factors would be essential. (There was no such requirement during the research period, as the author was aware of the bounds of demarcation and could ensure a uniformity of treatment.)

The risk analysis programme could also be developed further to cope more readily with the problem of multi-product plants and groups of plants within a complex. Of course there is a compromise to be struck here between the advantages of increasing the resolution of the evaluation, and the disadvantages of the costs of modelling and programming the detail, the additional computational costs, and the added difficulty of interpretation of results that is sometimes introduced. In contrast another possibility would be to simplify the calculations in the early stages of the projects development.

The efficiency of operation of the system could also be improved by maintaining the information on the financial prospects of each project on computer files. Regular updating would allow a very fast retrieval of the latest forecasts of return, uncertainty and sensitivities. Such project files would also provide the basis of a consideration of portfolios of research projects.

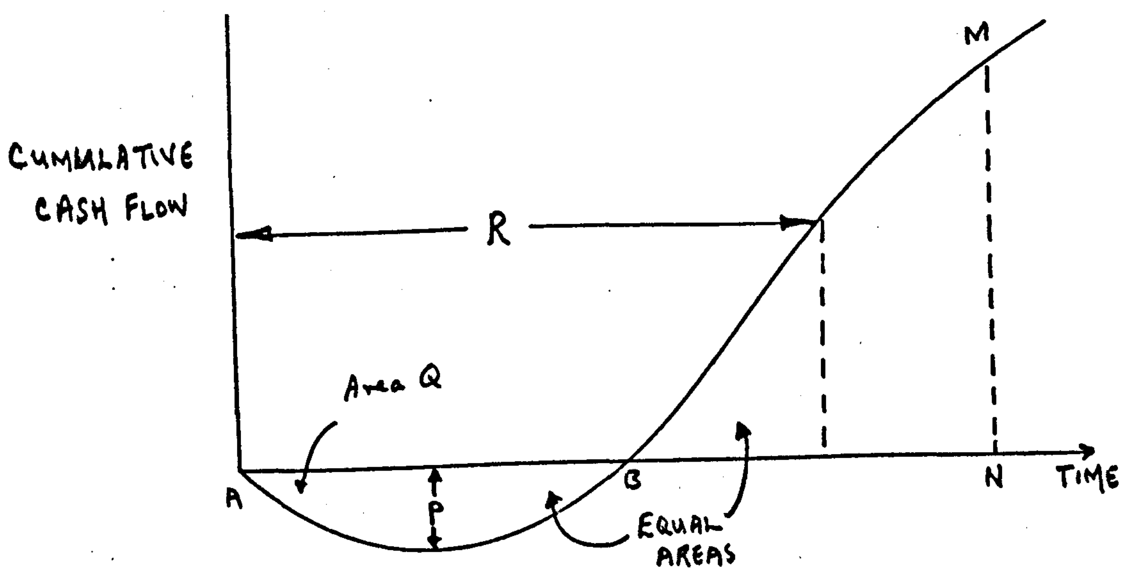
There are a number of areas where further research could be useful. With respect to the methods proposed, an important question concerns the validity of the data input to both checklists and risk analysis. More than anything else, validation requires time to enable forecast and achieved values to be compared over a number of variables and a number of projects . To a limited extent this may be done by looking at estimates made during the course of past projects, but only rarely may the relevant data be found. It would also be useful to examine alternative methods of classifying checklists and of estimating probability distributions of variables in the financial evaluation. (A different approach to the former is suggested in section 4.7.2). The introduction of the new system proposed would provide a sound basis for much of this work. In a rather different area, attempts to measure the utility functions (in the sense of Von Neumann and Morgenstern) of various levels of management could be made. This would lead to experiments with expected utility as a criterion of success.

Further research following up the work of Chapter 5, could include the development of a more refined set of project acceptance-rejection screens. A sequential programme of such screens proposed by Ansoff (11), in another context is worth examination in the research situation. For example, in addition to satisfying certain financial requirements such as payback or NPV, projects could be screened with respect to the type of synergy, competitive advantage or growth that is offered.

Appendix 1

SOME CRITERIA FOR EVALUATING RESEARCH PROJECTS

Figure 1



(1) Payback period.

The payback period is the number of years for the income attributable to the project, to just equal the investment. It is important, when the investment occurs over a number of years, to define the point the payback period is measured from. Two convenient points are (a) from the start of the investment, and (b) from the point of maximum investment. In Figure 1 above the former would be given by AB.

(2) Return on capital.

Return on capital is a measure of the efficiency by which income is generated from the capital employed. Different organisations will apply their own conventions with respect to the definitions of both income and capital and the point (in the life cycle of the investment) at which the measurement is to be made. The ratio used by ICI is:

$$\frac{\text{Net income - depreciation}}{\text{Total capital employed}} \times 100\%$$

(Total capital is the sum of fixed and working capital and the calculation is made with respect to the first year of full-scale operation).

(3) Net present value (NPV).

The net present value is the cumulative discounted cash flow at the end of a period. It is defined by the expression:

$$NPV = \sum_{i=o}^{N} \frac{S_i\,(P_i - V_i) - F_i - C_i - W_i}{(1 + r)^i}$$

where S_i: Sales of product in year i.

P_i: Selling price of product in year i.

V_i: Variable cost of product in year i.

F_i: Fixed cost of product in year i.

C_i: Capital cost of plant in year i.

W_i: Working capital introduced in year i.

r : Rate of interest (or discount) for the firm.

N : The number of years under consideration.

If, in Figure 1 the ordinate is cumulative discounted cash flow then MN would indicate the NPV of the project at time N.

It must be stressed that r is not simply defined, it is related to the costs of different forms of capital borrowing open to the firm, which in turn are bound to the general economic situation. The interest rate is therefore a function of time. Bierman and Smidt ((16) page 135) suggested a weighted average, of the cost of different sources of capital: equities, preference shares, debentures etc. Where the weight appropriate to source i is the ratio:

Market value of source i securities/Market value of company.

(4) Discounted cash flow rate of return (DCF).

The DCF rate of return is closely related to NPV; it is the value of r (the interest rate) which produces a NPV of zero. It is found by setting NPV = 0 and solving the above equation for the appropriate value of r.

(5) Equivalent maximum investment period and interest recovery period.

Definitions of these criteria are taken from Allen and Edgeworth Johnstone's paper (25). The equivalent maximum investment period is the area enclosed by the normalised cumulative cash flow curve, and the time axis between the origin and the breakeven point. The normalised cumulative cash flow was such that the minimum cumulative cash flow = -1. The equivalent maximum investment period thus is given by Q/P in Figure 1.

The 'interest recovery period' is a function of the area between the cumulative cash flow curve and the time axis. It is the time required to enclose an area above the axis equal to the area, below the axis, up to the breakeven point (R in Figure 1).

Appendix 1.1

SCORING MODELS: SOME OF THE IMPLICATIONS OF DIFFERENT METHODS OF COMBINING FACTOR SCORES.

In Section 1.2.1 it was suggested that one of the disadvantages of scoring models was that no one system of combining factor scores has a priori claims to general acceptance. Furthermore it is usual for different scoring systems to arrange groups of projects in different orders of merit.

The work to be described compares some of the implications of using addition and multiplication as means of combining factor scores. The simple model proposed by Mottley and Newton (Section 1.2.1) was taken as a base. This model scores five factors related to the success of research projects on the scale 0, 1, 2, 3; where the scores imply a poor, unforeseeable, fair or good performance with respect to the factor. The project score is then taken to be the product of the factor scores.

(1) Some immediate observations.

Simple arithmetic shows that under rules of multiplication, twenty two project scores are possible. These extend from 0 to 243 (i.e. 3^5). Some of these scores are more readily obtainable than others. For example the score 32 can only be achieved if each factor is assigned the value 2. In contrast the score 16 can be obtained in 5 ways. (Any one of the five factors may take the value 1, whilst the remaining four factors take the value 2). Table 1 (below) shows how the 1024 (4^5) permutations of five factors taking one of four values, are distributed across the twenty two possible project scores.

Table 1

Possible Scores	0	1	2	3	4	6	8	9	12	16	18	24	27	32	36	48	54	72	81	108	162	243
Frequency	781	1	5	5	10	20	10	10	30	5	30	20	10	1	30	5	20	10	5	10	5	1
Position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22

If addition is used to combine the factor scores, then only sixteen project scores are possible - the integers 0 to 15. Clearly the number of permutations of factor scores remains constant at 1024. These are distributed according to Table 2 below.

Table 2

Possible Scores	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Frequency	1	5	15	35	65	101	135	155	155	135	101	65	35	15	5	1
Position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

In both cases the frequencies were found by application of the formula:

$$n!/r_1!r_2! \text{ -----},$$

which gives the number of permutations of n items, r_1 of one class, r_2 of another class, etc. For example if the project score was 36 (i.e. 3 x 3 x 2 x 2 x 1), the number of permutations is given by 5!/2!2!1! = 30. (The calculation is slightly more complicated if scores are combined using addition). A number of conclusions may be drawn from these distributions and other considerations:

(i) The inclusion of zero as a possible score ensures that, under rules of multiplication, a 'poor' performance with respect to just one factor is sufficient to give a project score of zero. This is the reason for the predominance of zero scores in the distribution of Table 1. On the other hand, under rules of addition, a project with one factor scoring zero can still achieve a high project score. (For example the set of scores (0 3 3 3 3).)

(ii) Combination by multiplication allows projects to be classified into more boxes or compartments than combination by addition. The scheme based on multiplication therefore offers greater resolution.

(iii) Under multiplication, the possible project scores are distributed very unevenly between 0 and 243. Dividing the range into three intervals 0 to 81, 82 to 162, 163 to 243, the project may take one of 19 positions in the first interval, but only one of three positions in the combined second and third intervals.
Furthermore equal changes in factor scores can give rise to different changes in project scores. For example, suppose a project was scored (1 1 1 1 1), and over a period the first factor improves to be rated 2, then the project score moves from 1 to 2 - an increase of 1. But if the initial score had been (1 3 1 3 2), then increasing the value of the first factor score from 1 to 2 changes the project score from 18 to 36 - an increase of 18.
Under addition however, any score in the range 0 to 16 is possible and equal changes in factor scores give rise to equal changes in project scores. (In the first example an increase of 1 in the score of the first factor changes the project score from 5 to 6).

(2) The discriminative properties of the two methods of combining factor scores.

The assumption behind this exercise was that errors may arise when assigning factor scores. In this event incorrect conclusions concerning the project score, or the associated position of the project in the range of possible positions may be drawn. (Tables 1 and 2 relate project position to project score).

Two questions were considered:

(i) Given project A in position x, and project B in position y, what is the probability that the true position of x is higher than that of y?

(ii) How are the conclusions of (i) above affected by the method of combining factor scores.

Once again the Mottley-Newton model was taken as a test case. It was assumed that given the value of a factor score was s, then the assessor might score the factor s-1, s, or s+1, with probabilities 0.25, 0.5 or 0.25 respectively. (If $s = 0$, it was assumed the assessor would score the factor 0 or 1 with probabilities of 0.75 or 0.25. The score $s = 3$ was treated in the same manner as the score 0.)

A simulation model was used to attach a standard deviation to the position the model assigns to the project. (As will be demonstrated later, certain deductions concerning question (i) may be drawn from the standard deviation.) The simulation model can be divided into the following steps:

(a) Postulate a project score (e.g. 1 3 3 2 1).

(b) Take five random numbers (r_1 to r_5) from a sequence $0 \leq r_i \leq 1$.

(c) If $0 \leqslant r_1 < 0.25$, decrease the score of the first factor by 1.

If $0.25 \leqslant r_1 < 0.75$, the score of the first factor is unchanged.

If $0.75 \leqslant r_1 \leqslant 1$, increase the score of the first factor by 1.

(Scores of 0 and 3 are treated slightly differently of course- see above).

(d) Adjust factors two to five in the same way, according to random numbers r_2 to r_5.

(e) Calculate the project score by the appropriate rule (either addition or multiplication).

(f) Convert the project score into a project position.

(g) Repeat the process starting at (b) a large number of times. (On each occasion the next set of five random numbers in the sequence is taken)

(h) Calculate the mean and standard deviation of the set of project positions determined by steps (b) to (f).

Thus given a set of factor scores which define a project score and hence a project position, the simulation programme generates a distribution of project position. This distribution illustrates how errors in assigning factor scores affect the position that the model allocates to the project.

Table 3 summarizes the results of six computer runs. Three different sets of factor scores were postulated corresponding to projects with low, medium and high positions. The computer runs were made with each of the three sets of factor scores combined under rules of addition and multiplication. In each run 2400 simulations were made (these took about 3 minutes on an Elliot 4100 computer).

Table 3: The Computer runs

Run Number	Factor Scores	Combination Rule	Expected* Project Score	Expected + Project Position	Result after 2400 Simulations	
					Average Position	Standard Deviation of Position
1	0 1 2 2 3	x	0	1	2.54	3.40
2	0 1 2 2 3	+	8	9	8.99	1.362
3	1 1 2 3 3	x	18	11	7.16	6.01
4	1 1 2 3 3	+	10	11	10.48	1.363
5	2 2 2 3 3	x	72	18	15.88	3.54
6	2 2 2 3 3	+	12	13	12.48	1.363

* The expected project score is the combination of the expected factor scores under the appropriate rule.

\+ Tables 1 and 2 relate project position to project score.

It is clear that under rules of multiplication, the difference d between the expected position and the average position, and the standard deviation of position s were larger than under rules of addition. (Where the expected position is that achieved by combination of the expected factor scores). For example in run 1, d was 1.54 positions, compared with 0.01 positions in run 2. Similarly under multiplication, the smallest value of s was 3.4 positions (run 1) compared with 1.6 positions for the runs 2, 4 and 6. The largest value of s was $\sim$6 positions (run 3). This was a consequence of allowing factors to be scored zero: the simulated distribution of position was bimodal with a sharp peak at position 1 (i.e. score 0) and a broader peak around position 11 (i.e., score 18 - the expected score).

Under rules of addition the value of s (i.e., 1.36 positions) is shown to be independent of factor scores. This is to be expected as changing the factor scores simply translates the distribution of position, it does not change its shape. (Assuming that the 'end-effects' of the limited range of factor scores are ignored). 'End-effects' failed to show through in the examples of Table 3 (runs 2, 4 and 6), because of a coincidence. Each of the postulated scores contained two extreme values (i.e. 0's or 3's), the 'end-effects' of each were therefore the same.

Returning now to questions (i) and (ii) above concerning project A in position x and project B in position y. Basic statistics, (see for example Davies (67), page 53), indicates that the standard error of the difference of position (i.e., x-y) is given by $(S_1^2 + S_2^2)^{\frac{1}{2}}$, where S_1 and S_2 are the standard deviations associated with the scores x and y. If it is assumed that under rules of addition $S_1 = S_2 =$ 1.36 positions and that scores are distributed normally, then the standard error of (x-y) is given by $\sqrt{2} \times 1.36 = 1.92$. Similarly if it is assumed that under rules of multiplication $S_1 = S_2 = 3.4$ positions, then the standard error is given by $\sqrt{2} \times 3.4 = 4.8$ positions. (Note that the above assumptions are the most optimistic the runs of Table 3 permit - i.e., are those that provide the lowest standard error of the mean).

Some of the conclusions that may be drawn from the standard error are summarized in Table 4 below:-

Observed Difference of Position (x - y)	Probability that the true position of A is higher than that of B	
	Combination by addition	Combination by multiplication
0	.500	.500
1	.699	.582
2	.851	.661
3	.941	.734
4	.981	.797
5	.995	.851
6	.999	.894

Thus, for example, if the model assigns projects A and B the same position, then under rules of combination by either addition or multiplication, there is a .5 chance that the true position of A is higher than that of B. On the other hand, if project A is assigned position 9 and projectBposition 6 (i.e., (x-y) = 3), then under rules of addition the probability that the true position of A is higher than that of Bis.941. Under rules of multiplication, however, the corresponding probability is only .734.

By showing that the conclusions with respect to questions (i) are dependent on the method of combination of factor scores, Table 4 also answers question (ii). It is also important to stress, in passing, that the above results are also strongly dependent on the assumptions concerning the error in assigning factor scores.

Appendix 2

AN ESTIMATE OF THE RETURN ON R & D EXPENDITURE

During the course of research on project E, Mond Division was buying in the intermediate and providing the suppliers with valuable business. There is good reason to believe, that these suppliers, aware of Mond Division's research efforts, did not wish to encourage the Division to install its own source of supply. One means of doing this was to offer future supplies of the intermediate at a more attractive price. (Either by accepting a reduced profit margin, or by improving the manufacturing process or, in the longer term, by developing new processes.) In the calculations to be discussed, the basic assumption was that over the period of ten years from year 9 to year 18, the cost of the intermediate to Mond Division would be lower, because of the bargaining position gained by research.

Three calculations were made with ΔC, the decrease in cost, equal to 5%C, 10%C, 15%C; where C is the forecast cost of the intermediate. The saving S, attributable to these cost reductions, was determined and set against the research expenditure over years 1 to 8. Finally, the DCF rate of return of (savings - research expenditure) was calculated over years 0 to 18. The financial data used in the calculations were those of the latest estimates of Figures 2.4 and 2.5 (i.e. 1.7.9 for demand and 1.7.8 for cost). Where official estimates did not cover the whole period over which savings were considered, some extrapolations were made, these are indicated by the dashed lines in the Figures. The research expenditure was taken from the profile of Figure 2.3.

Figure 1 summarizes the calculation, in the case when ΔC = 15%C, and Figure 2 is a plot of the results. It is shown that it is only necessary for a cost reduction of ∿3.5%C for savings to cover the cost of research and that a 15% DCF rate of return would have been achieved if the cost of the intermediate had been forced down by ∿12%C. These calculations show that it is not unreasonable to claim a modest return on research expenditure even allowing for the basic assumption, and the general unreliability of the data.

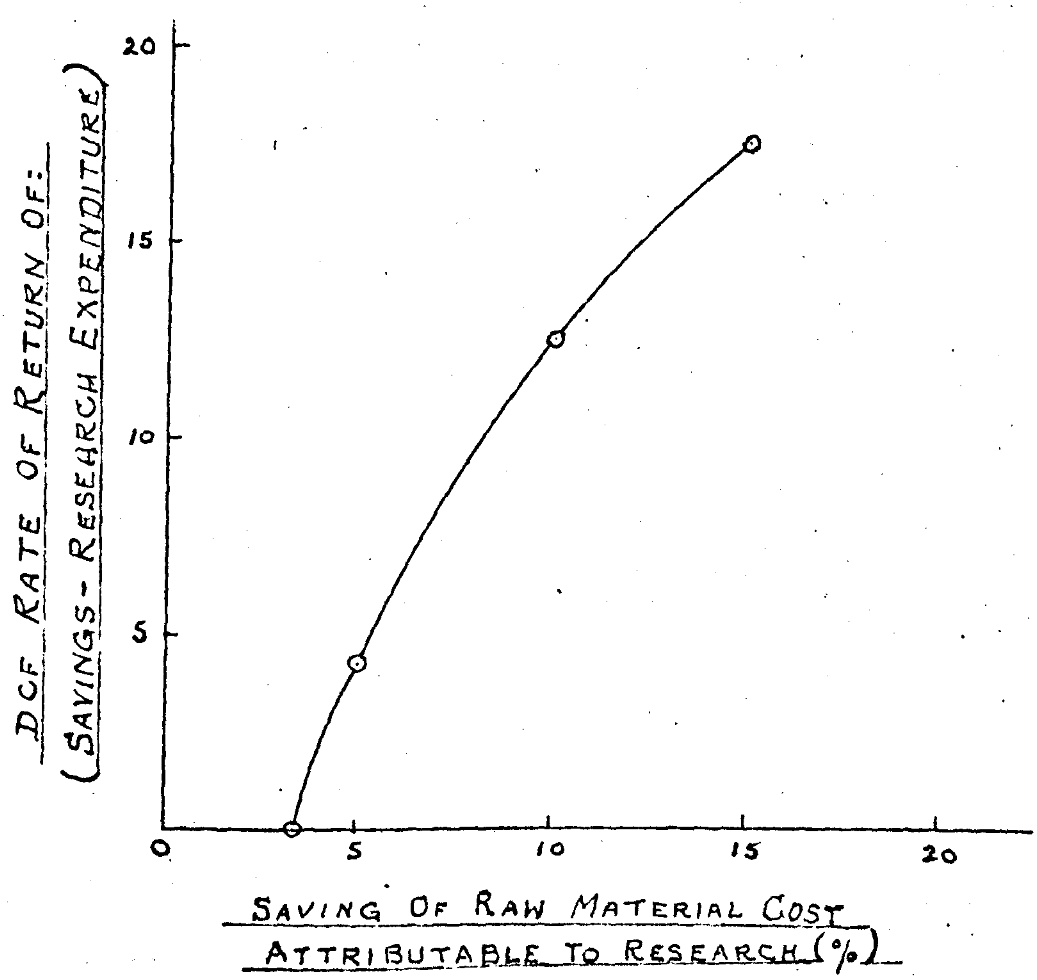
Moreover, as explained in the text, the research also satisfied the important 'insurance of supply' objective. If the foregoing analysis is realistic, then the insurance was secured for zero or negative premium payments.

Figure 7

NPV of Savings attributable to R & D Expenditure (Assuming ΔC = 15%C)

Year	Research expenditure (£k)	Demand D of intermediate (ton/yr)	Cost C of intermediate (£/ton)	Savings 0.15 x D x C (£k)	Net cash flow (£k)	Discount factors (17%)	Discounted cash flow (£k)	Cumulative cash flow (£k)
0	0				0	1.0	0	0
1	1.25				-1.25	0.855	-1.07	-1.07
2	4.40				-4.40	0.731	-3.22	-4.29
3	1.90				-1.90	0.624	-1.18	-5.47
4	1.75				-1.75	0.534	-0.94	-6.41
5	5.35				-5.35	0.456	-2.44	-8.85
6	7.85				-7.85	0.390	-3.06	-11.91
7	7.80				-7.80	0.333	-2.6	-14.51
8	3.00				-3.00	0.285	-0.86	-15.37
9		300	106	4.76	4.76	0.243	1.16	-14.21
10		400	105	6.30	6.30	0.208	1.31	-12.90
11		540	104	8.44	8.44	0.178	1.50	-11.40
12		670	100	10.04	10.04	0.152	1.53	-9.87
13		972	96	13.96	13.96	0.130	1.81	-8.06
14		1166	92	16.08	16.08	0.111	1.78	-6.28
15		1400	88	18.46	18.46	0.095	1.75	-4.53
16		1600	85	20.40	20.40	0.081	1.65	-2.87
17		1800	82	22.20	22.20	0.069	1.53	-1.34
18		2000	79	23.60	23.60	0.059	1.39	+0.05

FIGURE 2 : DCF RATE OF RETURN OF RESEARCH EXPENDITURE.



Appendix 3

SOME TESTS ON THE RISK ANALYSIS PROGRAMME

Before the programme was used on a routine basis some tests were made to obtain a feel for the technique.

(1) The Convergence of the Distribution of Project Return.

Risk analysis is a method of generating the distribution of project return Φ. It can be shown that as the number of simulations n increases, the distribution generated Φ', becomes a closer approximation to Φ. If NPV is the criterion measuring project return, then after n simulations the best estimates of the mean and standard deviation of Φ (the distribution of NPV), are given by respectively:

$$\bar{x} = \sum_{i=1}^{n} x_i/n \text{ and } s = \left(\sum_{i=1}^{n} (x_i - \bar{x})^2/(n-1)\right)^{0.5}$$

where x_i is the NPV of the ith simulation.

If it is assumed that Φ is normal, then a confidence interval may be placed on μ, the mean of Φ. The 95% confidence interval is given by

$$\bar{x} - \Delta \leqslant \mu \leqslant \bar{x} + \Delta$$

where $\Delta = t_a s/\sqrt{n}$, and t_a is the appropriate value of the t-distribution (see Davies (67), page 53). When n is large the t-distribution approximates closely to the normal distribution and $t_a = 1.96$ (when n = 10, $t_a = 2.23$; when n = 100, $t_a = 1.99$).

The expression for Δ shows that as $n \to \infty$, $\Delta \to 0$; thus by increasing n, the confidence interval around μ may be progressively smaller.

A compromise must therefore be achieved between the precision of the estimate of Φ and the cost of computer time. In this respect it is important to note that the cost of the latter increases linearly with n, but the rate of convergence of the confidence interval becomes progressively slower, because Δ is porportional to $1/\sqrt{n}$.

Figure 1 shows how the 95% confidence interval on the mean, varied with n in an actual case; the results are reproduced graphically in Figure 2. Another point which was examined, as a formality, was the dependence of the distribution of project return on the random number sequence. (Random number sequences, generated by computers, require a starting number to initiate the sequence, and different starting numbers generate different sequences). Figure 2 includes the results of repeating run 5 of Figure 1, using different sequences of random numbers. As might be expected, the three values of the mean (runs, 10, 11, 12) all lie within the 95% confidence interval of the mean of the run 5.

Figure 1

SOME RUNS TO EXAMINE THE CONVERGENCE OF THE MEAN

Run No.	No. of simulations n	No. starting random no. sequence	$\bar{x}$	s	t_a	95% confidence interval on $\bar{x}$ $(t_a s/\sqrt{n})$
1	20	7	-152.0	±56.7	2.09	±26.5
2	50	7	-151.7	±57.8	2.01	±16.4
3	75	7	-157.4	±55.7	2.00	±12.9
4	95	7	-159.5	±57.1	1.99	±12.0
5	100	7	-164.1	±57.7	1.99	±11.5
6	110	7	-162.4	±56.5	1.98	±10.7
7	150	7	-160.9	±58.1	1.97	± 9.4
8	500	-	-160.9	±58.1	1.96	± 5.1*
9	1000	-	-160.9	±58.1	1.96	± 3.6*
10	100	9	-157.2	±61.5	1.99	±12.2
11	100	13	-162.5	±54.9	1.99	±10.9
12	100	5	-160.8	±58.4	1.99	±11.6

* These are estimated figures and assume $\bar{x} = -160.9$ and $s = \pm 58.1$ (see run 7)

(2) The Sensitivity of the Project Return to the Estimate of Confidence Interval

The treatment of uncertainty using the method of risk analysis, depends to a very large extent on the ability of personnel to make estimates of confidence intervals surrounding the mode values of variables. Suppose for example that, instead of giving a set of 95% confidence limits on a variable, the respondent gives a 90% interval. The project assessor runs the computer programme on the assumption that a 95% interval has been estimated, and consequently the uncertainty calculated by the risk analysis is an underestimate.

The extent of errors, introduced in this manner, was investigated by making the assumption that x%, instead of 95%, confidence intervals were estimated on each variable. Run 5 of Figure 1 was then repeated with x taking the values of 80%, 90% and 99.7%. (The latter was chosen because the 99.7% confidence limits of a normal distribution are close to six standard deviations apart.) The results are presented in Figure 3, it is clear that if errors of interpretation of this type are made, then considerable differences between the 'real' uncertainty, and the uncertainty calculated by the programme can arise. Since the estimates of confidence interval must be highly subjective, the value of the uncertainty of project return must be treated with caution. Figure 4 shows that so long as the mode values of the normal distributions are estimated consistently, the value of the mean project return is largely unaffected by errors in the estimation of confidence interval.

(3) The Effect of Fitting Rectangular Distributions to the Data.

Though, intuitively, for the purposes required, the normal distribution has more suitable properties than the rectangular distribution, it was considered useful to examine the result of fitting rectangular distributions to the data subject to uncertainty. The object was to illustrate how the estimate of project uncertainty was dependent on the choice of distribution fitted to the basic data (the estimates of mode and 95% confidence limits). Run 5 of Figure 1 was again taken as a test case, and rectangular distributions were fitted so that the end points of the distribution and confidence interval coincided. The distributions of project return in the two cases are presented in Figure 5.

It is clear that under the assumptions the effect was not great. The mean value of the project return increased slightly from -164.1 for run 5 to -167.4. The distribution produced by the rectangular distributions was flatter than that produced by the normal distributions, a fact that was reflected by an increase in standard deviation from $\pm$ 57.7 for run 5 to $\pm$ 62.7. On the other hand, the maximum width of the distribution was less, and was reduced from 317.9 to 251.9. The latter is easily explained, as the rectangular distributions restrict variables to take values between the upper and lower confidence limits only.

More pronounced differences may be obtained by making different assumptions. For example, if the end points of the rectangular distributions were made to coincide with the 99.7% confidence limits of the corresponding normal distributions, then clearly the resulting distribution of project return would have a greater spread.

Such considerations simply underline the need for caution when drawing conclusions concerning the project uncertainty.

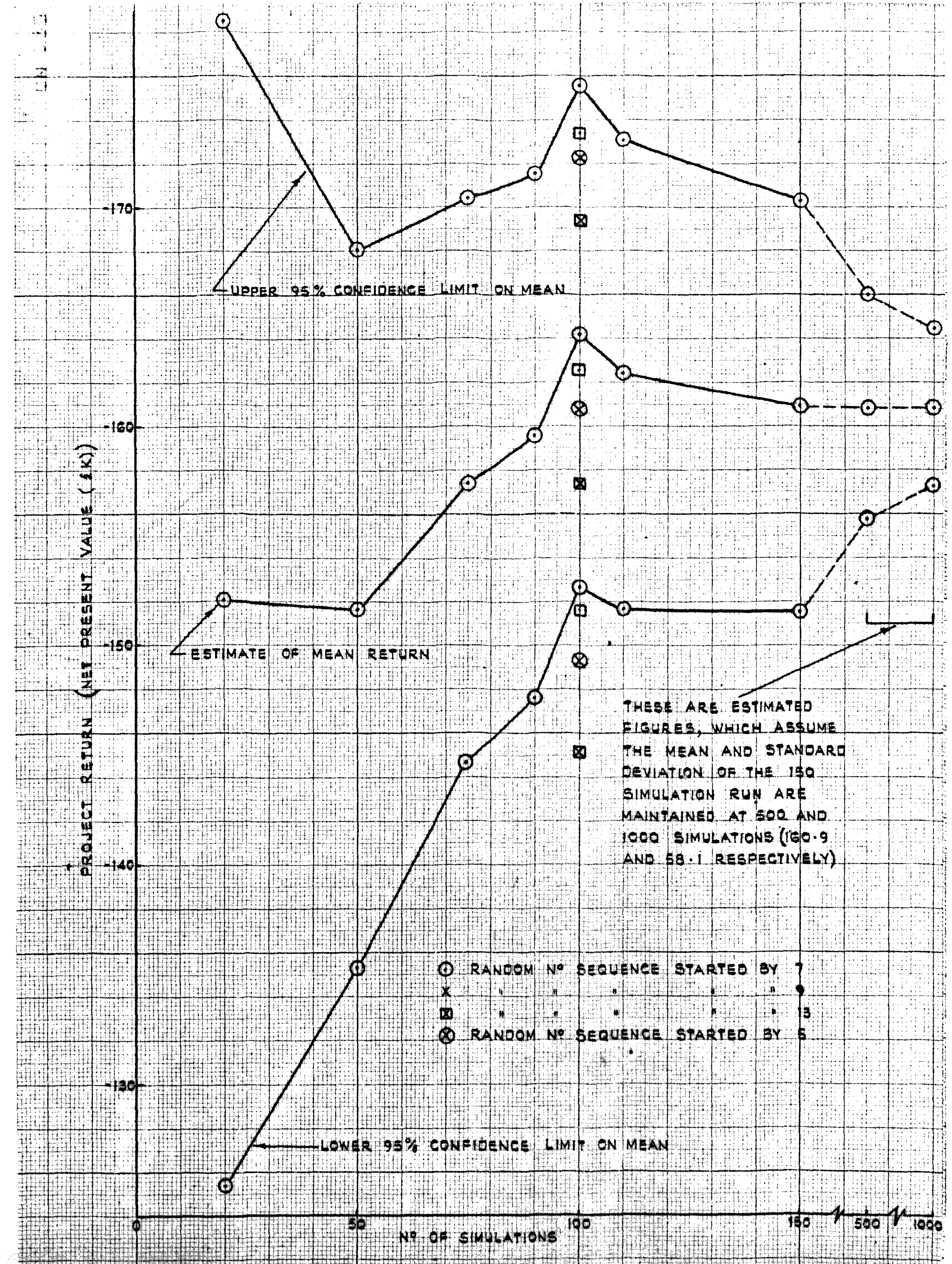


FIGURE 2. CONVERGENCE OF A RISK ANALYSIS CALCULATION

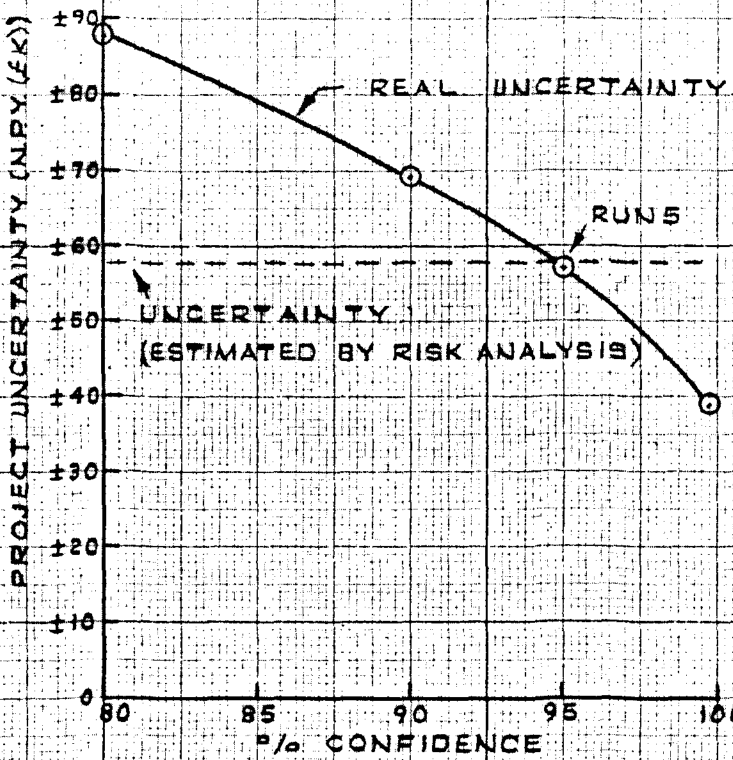


FIGURE 3.

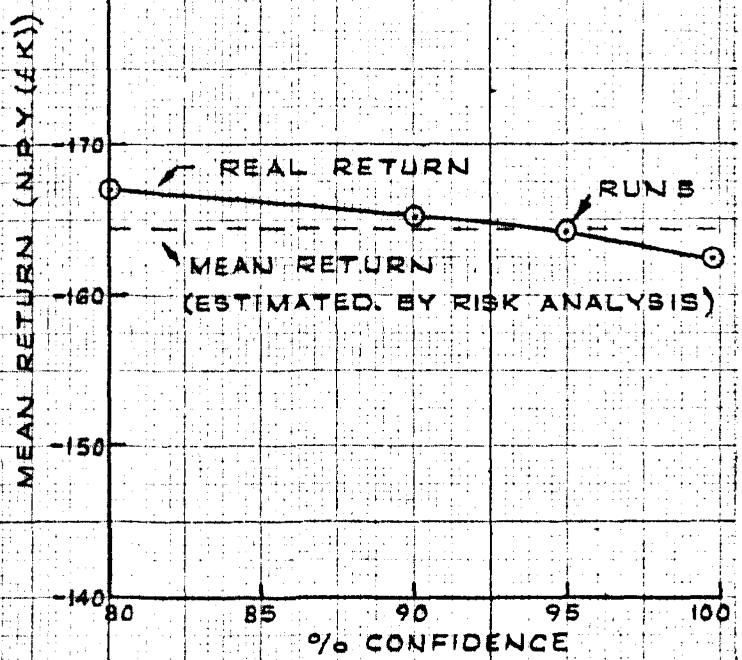


FIGURE 4

THE EFFECT OF ERRORS IN INTERPRETATION OF CONFIDENCE INTERVALS ON (i) UNCERTAINTY (FIGURE 3.) AND (ii) RETURN (FIGURE 4)

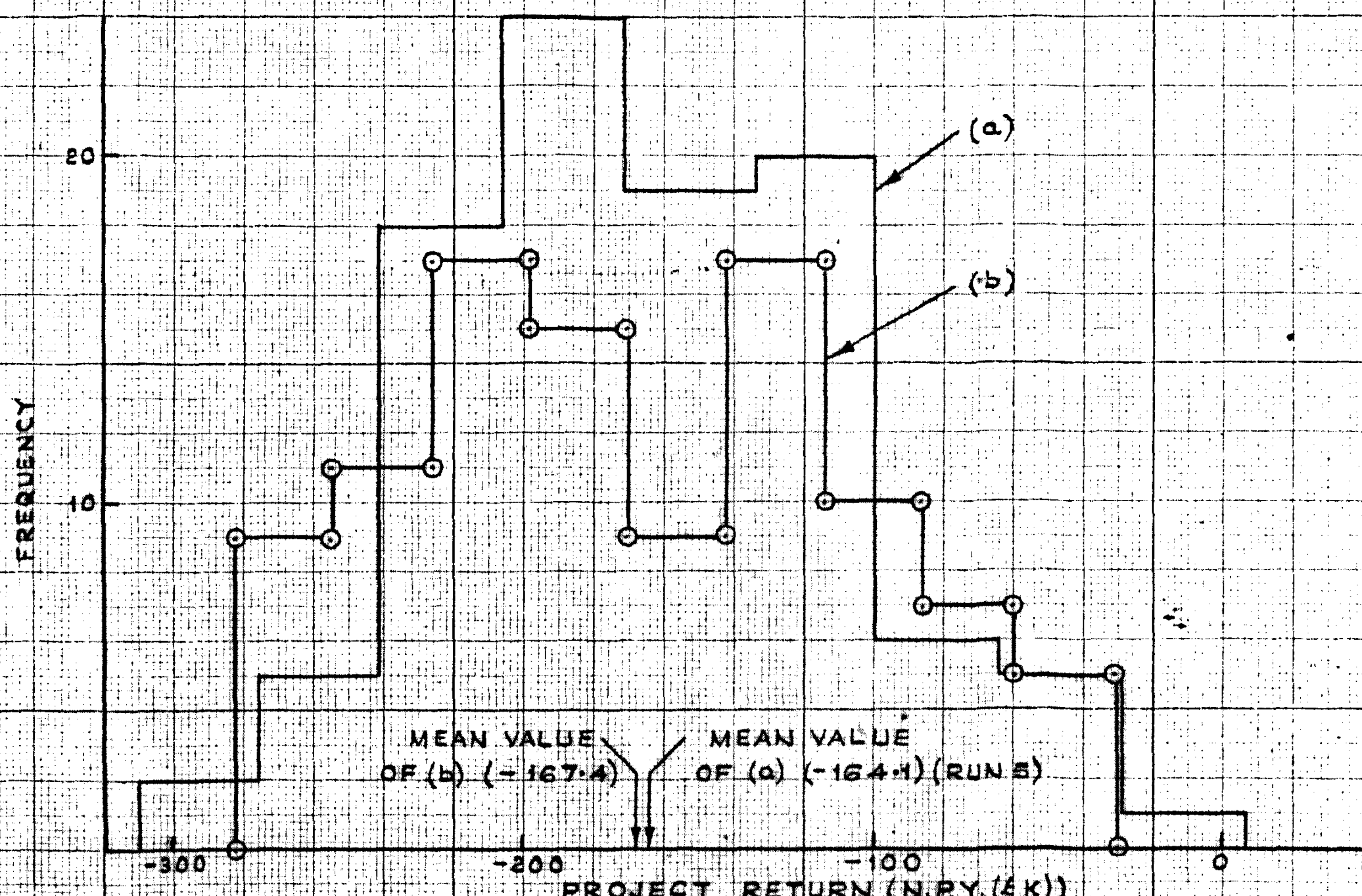


FIGURE 5

THE DISTRIBUTION OF PROJECT RETURN WITH UNCERTAINTY REPRESENTED BY (a) NORMAL AND (b) RECTANGULAR DISTRIBUTIONS

Appendix 4

THE EXTENSION OF THE RESULTS OF THE SENSITIVITY ANALYSIS.

When the values of variables in the financial criterion are changed, the mean and uncertainty (standard deviation) of the distribution of project return are also changed. The extent of the change may be estimated by rerunning the risk analysis programme with new input data, or more simply by applying the results of the sensitivity analysis (see Section 3.3.2 and Figure 4.11). This Appendix suggests how the results of the sensitivity analysis may be interpolated, or extrapolated, and presents some supporting examples.

(1) The Change in mean return due to the change in the mean of a variable

In Appendix 1, the NPV of a project was defined by an expression of the form:

$$NPV = \sum_{i=o}^{N} \frac{S_i(P_i-V_i) - C_i-F_i-W_i}{(1+r)^i}$$

The sensitivity of the project return (NPV) to a change in one of the variables was found by changing the value of the variable by 10% and noting the change in the NPV (see Section 3.3.2). Normally a selection from the variables S_i, P_i, V_i, C_i or F_i, would be considered in a sensitivity analysis. For example, if the sensitivity of the project return to capital cost in year 1 was required, then the change in NPV for a 10% change in C_1 would be determined. On the other hand the sensitivity of the return to capital cost, in general, would be found by changing C_i by 10% for all i. Under both of these assumptions, for a given discount rate r, the expression for NPV is linear in the variable under examination.

Linear interpolation or extrapolation, may therefore be used to extend the results of the sensitivity analysis, to give the change in the mean return for a change in the value of one of the variables. However it must be ensured that the changes do not violate the basic assumptions of the evaluation. For example the demand (S_i) must not be allowed to exceed the available production capacity.

(2) <u>The change in project uncertainty due to a change in the uncertainty of one of the variables.</u>

For convenience the expression for NPV is written NPV = $f(x_1, x_2, \ldots x_n)$. The variance (the square of the standard deviation) of the NPV is then given (to a good approximation) by:

$$\text{var(NPV)} = \text{var}\,(x_1)\,\left(\frac{df}{dx_1}\right)^2 + \text{var}\,(x_2)\,\left(\frac{df}{dx_2}\right)^2 + \ldots\ldots\text{var}\,(x_n)\,\left(\frac{df}{dx_n}\right)^2, \ldots\ldots(i)$$

where var (x_1) represents the variance of variable x_1, etc. (See Davies (67), page 41). This expression may be used as a guide to interpolating the results of the sensitivity analysis on the project uncertainty.

Suppose U_o is the uncertainty of the project in the base case, and U_1 is the uncertainty of the project with variable x_1 set at its mean value. Then, ΔU in the sensitivity analysis (Figure 4.11) is defined by $U_o - U_1$. From (i) above, the variance of the base case is given by:

$$U_o^2 = \text{var}\,(x_1)\,\left(\frac{df}{dx_1}\right)^2 + \text{var}\,(x_2)\,\left(\frac{df}{dx_2}\right)^2 + \ldots\ldots\ \text{var}\,(x_n)\,\left(\frac{df}{dx_n}\right)^2 ,$$

and by definition of the sensitivity analysis, if variable x_1 is under examination, then var $(x_1) = o$ (since x_1 is fixed at its mean value) and

$$U_1^2 = \text{var}(x_2) \left(\frac{df}{dx_2}\right)^2 + \text{var}(x_3)\left(\frac{df}{dx_3}\right)^2 + \ldots\ldots \text{var}\ x_n \left(\frac{df}{dx_n}\right)^2 .$$

$$\text{Thus, var}(x_1) \left(\frac{df}{dx_1}\right)^2 = U_o^2 - U_1^2 , \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(ii)$$

is the contribution of variable x_1 to the variance of the base case. Now suppose it is required to estimate the effect of reducing the 95% confidence interval on variable x_1 by p_1% (instead of by the 100% of the sensitivity analysis). The contribution C of variable x_1 to the variance of the project is then given by:

$$C = \text{var}(x_1)\ (1-p_1/100)^2\left(\frac{df}{dx_1}\right)^2,$$

where var (x_1) is the variance of variable x_1 in the base case. From (ii), $C = (U_o^2 - U_1^2)\ (1 - p_1/100)^2$, and hence the associated variance of NPV is given by:

$$\text{var (NPV)} = (U_o^2 - U_1^2)\ (1 - p_1/100)^2 + U_1^2 .$$

As the standard deviation of the project return has been used to measure uncertainty, the change in uncertainty ΔU (from the base case) due to a p_1% reduction in the 95% confidence interval on variable x_1 is given by :

$$\Delta U = U_o - \left\{(U_o^2 - U_1^2)\ (1-p_1^2/100)^2 + U_1^2\right\}^{\frac{1}{2}} \qquad \ldots\ldots\ldots\ldots(iii)$$

This formula was tested by comparing the ΔU's determined from (iii), with those determined by use of the risk analysis programme. In the case considered U_o, the uncertainty of the project, in the base case was £57.7k. With one of the variables fixed at its mean value (i.e., with a 100% reduction of the confidence interval on this variable), the sensitivity analysis gave U_1 = £28.8k, and thus ΔU = £28.9k. The change in uncertainty for 25%, 50% and 75% reductions of the confidence interval on the variable was then determined using both formula (iii), linear interpolation, and the risk analysis programme. The results are presented in the Figure 1 below.

Figure 1

p	Δ U		
(% reduction of 95% confidence interval)	Calculated using the risk analysis programme	Estimated from (iii) above	Estimated using linear Interpolation.
0(base case)	0	-	-
25%	9.7	10.4	7.2
50%	19.2	19.6	14.4
75%	26.2	26.3	21.7
100%(sensitivity analysis calculation)	28.9	-	-

It is clear from the Table that in the case considered formula (iii) offered a reasonable approximation to the Δ U's. Furthermore the estimates based on (iii) were much superior to estimates based on linear interpolation.

(3) Changes in more than one Variable.

The results described above refer, of course, to changes in just one variable (e.g., capital cost). If it is required to estimate the changes in either the project return or uncertainty owing to changes in more than one variable, then the scope of the sensitivity analysis approach described above is considerably reduced. Though as was shown in some tests the analysis can provide a rough guide

Appendix 5

ANSOFF'S BOOK CORPORATE STRATEGY (11)

The opening Chapters of the book set the scene, decisions are broken down into the classes: administrative, operating and strategic. The book is principally concerned with strategic decisions which, it is claimed, have usually received insufficient attention in the past. It is then argued (Chapter 2) that 'capital investment theory' is inadequate to cope with strategic decisions and that a fresh approach is necessary. The following four chapters are devoted to a discussion of objectives and strategy. On page 44, objectives are stated to be measures of efficiency of the resource conversion process. Three elements are required to define an objective, the attribute which is chosen to measure efficiency, a scale of measurement, and a 'goal' value which the firm seeks to attain. Later on the 'goal' value concept is extended to include a 'threshold' value (page 50) which is the minimum acceptable level of performance with respect to the objective.

Ansoff recognises that normally, an organisation has a variety of objectives. In Chapter 4 he proposed a hierarchy in which short term and long term objectives are distinguished. Because of the problems of forecasting, it is assumed that only the former can be conveniently handled in terms of well known financial criteria. (e.g. NPV, DCF, rate of return), and that the latter must be measured by indirect means. The use of 'proxy', or lower level objectives, are suggested for this purpose; the essential point is that proxy objectives are readily measurable, and that together they may be regarded as pointers to the achievement of the objective they characterize. Thus the proxy objectives describing the long term objective 'growth' could be:

Growth of Sales,

Growth of Market Share,

Growth of Earnings,

Growth of Product Line.

Amongst the long term objectives of the organisation that require further definition are:

External Flexibility: This is related to the organisation's ability to react to external pressures (e.g. customers or competitors), or influences (e.g. advances in technology).

Internal Flexibility: This is related to efficiency of utilisation of the firms resources (e.g. profit/capital employed).

Stability: This is related to the existence of cyclical patterns, or other inbalances, that may arise (e.g. in sales or production).

Strategy is introduced in Chapter 6, Ansoff visualises strategy as providing the 'common thread' or theme that describes the business the firm is in and the business it wants to enter; it thus provides guidelines and imposes constraints on the selection of new projects. Four components are used to define strategy: product-market scope, growth vector, competitive advantage and synergy. The product-market scope lists the set of products and markets the firm wishes to develop. The growth vector defines the direction in which growth is required in terms of products and missions. It is most simply discussed in terms of the diagram below (page 99). (The mission refers to the customer need that the product satisfies).

Product / Mission	Present	New
Present	Market penetration	Product Development
New	Market development	Diversification

Later on (page 116) diversification is further subdivided into the classes: horizontal and vertical integration, concentric and conglomerate diversification. (The latter distinguishes between cases where there is a tenuous thread through either the market or technology (concentric diversification) and cases where there is no common thread (conglomorate diversification)). The competitive advantage component of strategy specifies areas where the firm makes a deliberate attempt to achieve an advantage over competitors, for example, control over entry might be sought by requiring projects to have a strong patent position or to have a high cost of entry. Alternatively, control over the market might be attempted, by marketing products of outstanding cost-effectiveness, or by only launching in areas where marketing 'know-how' is supreme.

When a new project is begun, it interacts with a number of departments and subdivisions of the organisation. Synergy is a property of some of these interactions, and is manifest when resources are such that they may be employed to the mutual advantage of the project and the firm. It is sometimes called the '2 + 2 = 5' effect to emphasise the point that, synergy implies that the value of the organisation and the project is greater when taken together, than when taken independently.

The synergy component of strategy therefore defines areas where the firm is strong and resources may be deployed to the advantage of the project, or areas where the firm is weak to encourage selection of projects which will reduce, or remedy, the weakness. In the former case, the interaction is 'from the firm to the project' and in the latter 'from the project to the firm'. If the effect is equally dependent on the project and the firm, then it is termed 'joint'.

Ansoff also found it useful to distinguish the manner in which the effect is achieved by introducing the terms 'investment', 'operating', and 'timing' synergy. These terms indicate that because of the special characteristics of the organisation and the project, the investment, or the time to come into full production, or the operating costs, are below what might be considered to be the norm.

On page 100, Ansoff gives an example of the objectives and strategy of a hypothetical chemical firm:

(1) Objectives: Return on investment: Threshold 10%, goal 15%.

Sales growth rate: Threshold 5%, goal 10%.

(2) Strategy: Product-market scope: Basic chemicals and pharmaceuticals.

Growth vector: Product development and concentric diversification.

Competitive advantage: Patent protection and superior research competence.

Synergy: Use of the firm's research capabilities and production technology.

The remainder of the book is concerned with a procedure for formulating a product-market strategy for the firm. This begins with 'internal appraisal': objectives are set and the 'gap' is determined between the aspirations (as expressed by the objectives) and the achievements possible, from the existing business. There is provision for revising objectives up or down, so that the procedure may always be terminated after 'internal appraisal'. However, in the event of a significant 'gap', it is more likely that the analysis would be extended to include 'external appraisal'. This considers diversification as a means of filling the 'gap'. A list of product-market portfolios is drawn up and the implications of each on the 'gap' is examined. The product-market portfolio which fills the gap in the most efficient manner is then taken to be the product-market strategy of the organisation.

The main tool for assessing the relative merits of the different portfolios is suggested to be a scoring model which takes account of achievement of objectives and compliance with strategy.

The final Chapter is devoted to the problems of project selection and organisation for corporate strategy. A flow diagram (page 182) summarizes the approach to the former. Projects are submitted to a series of screens, first on objectives and then on strategy. Projects passing these screens are then evaluated using the scoring model and a new set of current projects and a 'reserve' list are selected.

The purpose of the book (page 22) was to provide a practical framework for strategic decisions, rather than to provide a set of procedures for immediate use. Thus the scoring model and the various checklists are only described in general terms, and require adaption to meet the special needs of organisations wishing to apply them.

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