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**MANAGING DIVERSITY:
THE STRATEGIC PLANNING OF LONG TERM
TECHNOLOGY INFRASTRUCTURE**

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ABSTRACT

Current methods of addressing uncertainty in the field of technology planning and management rely heavily on the use of forecasting and scenario generation. However, current developments in the planning and systems literature suggest that concepts of diversity and resilience provide an alternative framework for addressing uncertainty. Consequently, this thesis adopts an interdisciplinary approach to investigate three specific aspects of the technology assessment process; the limits to information from quantitative modelling, technological and managerial strategies for combating uncertainty, and the roles of models and modellers in these strategies. As a preface to the study, the nature of resilience in the context of technology planning is reviewed and some propositions are made concerning the matching of planning tools with levels of management sovereignty. A series of simulation models developed as part of the research programme provide some useful insights into the role of diversity in promoting both reduced costs and greater cost stability over the long term. However, they also expose a number of methodological limitations to modelling diversity in technological systems. These limitations are associated with both the representation of diversity and the exposure of multiple solutions. The second strand of investigation shows that the flexibility promoted by managers active in a turbulent operating environment, is focused on organisational and human centred attributes of the firm's activities. The final research activity shows that professional modellers in the U.K. appear to be aware of the limitations of the tools and techniques they utilise and perceive their role as being one of providing a rational / scientific approach to problem solving. Both policy and methodology related conclusions are drawn from the three research activities. Integration of the various strands of the research results emphasises the importance of matching the strategic and decision issue contexts of a policy issue to the analysis and policy tools used. Several recommendations for further research are also provided.

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Finally, thanks to my mother and father for furnishing a faith in learning; and Sigi for furnishing a faith in me.

"It is unavoidable to the greatest part of men, if not all, to have several opinions without certain and indubitable proofs of their truth; and it carries an imputation of ignorance, lightness or folly, for men to quit and renounce their former tenets presently upon the offer of an argument which they cannot immediately answer and show the insufficiency of; it would, methinks, become all men to maintain peace and the common offices of humanity and friendship in the diversity of opinions, since we cannot reasonably expect that any one should readily and obsequiously quit his own opinion, and embrace ours with a blind resignation to an authority which the understanding of man acknowledges not."

John Locke (1632-1704)

"Necessity is something which exists in the mind, not in objects."

David Hume (1711-1776)

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CHAPTER 1

INTRODUCTION TO THE STUDY: INCENTIVES, AIMS AND SCENE SETTING.

1.1 The planning and management of technological infrastructures.

This introductory chapter seeks to achieve two aims. Firstly, to provide some background to the research programme, and secondly to outline the main issues to be addressed in later Chapters. The opening sections are concerned with a brief overview of the study's subject matter and an exploration of some of the key concepts which underlie the issues being investigated.

Overall, the study constitutes an interdisciplinary approach to technological infrastructure planning (the intended meaning of 'interdisciplinary' is discussed in Section 1.5), and is broadly concerned with planning for and managing resilience with applications to technological systems. Technology planning or technology assessment can involve a number of different aspects such as cost, environmental impact and logistics problems. The term technology planning is used throughout this study to denote the activity of assessing the performance of an intended technology or set of technologies. Technology assessment is avoided as a term due to its connotations with wider aspects of social and environmental utility. The study reported here is focused on a limited set of problems concerning the modelling of cost elements of technological systems under conditions of turbulence and associated aspects of developing strategies for technology investment and management under these conditions.

A case is made in Section 1.2 for sustainability being a desirable objective for the type of infrastructures being addressed in the study. Chapter 2 develops this proposition by exploring the determinants of sustainability, in particular resilience, diversity, flexibility and adaptability. Following on from these theoretical developments, three distinct research activities are reported, each one designed to investigate a particular aspect of the use of resilience as a tool for assessing technological infrastructures. The activities comprise the following:

- Modelling of diversity in technological systems.
- A survey of management operating in a turbulent environment.
- A survey of the attitudes of Operational Research (O.R.) professionals in the U.K. to the tools that they utilise.

In the final three chapters the methodological and policy related aspects of the research findings are collated and an integrated framework for addressing problems of long term technology planning is proposed.

Relevant terms and their intended meaning within the context of the study are discussed in more detail in this and the following chapter.

1.1.1 Introduction to the subject matter.

Most research on technological infrastructures has addressed the subject from the standpoint of the firm in a competitive environment (Tassey, 1991; Weiss & Birnbaum, 1989). These studies are typically concerned with identifying suitable innovation and investment policies for companies functioning in technologically intensive operating environments. This research project takes a slightly altered approach by focusing on a specific class of industries (typically large public utilities), and investigating issues of long term technology cost performance in an uncertain environment (as characterised by turbulent operating conditions). It has been noted that many recent studies on infrastructure planning have raised the issue of redefining the field from a purely physical systems to a social systems perspective (Haynes & Krmeneč, 1989). The question of planning technological infrastructures for public utilities, provides a relevant emphasis for such a change of perspective and this study investigates one approach to the assessment of technological infrastructures.

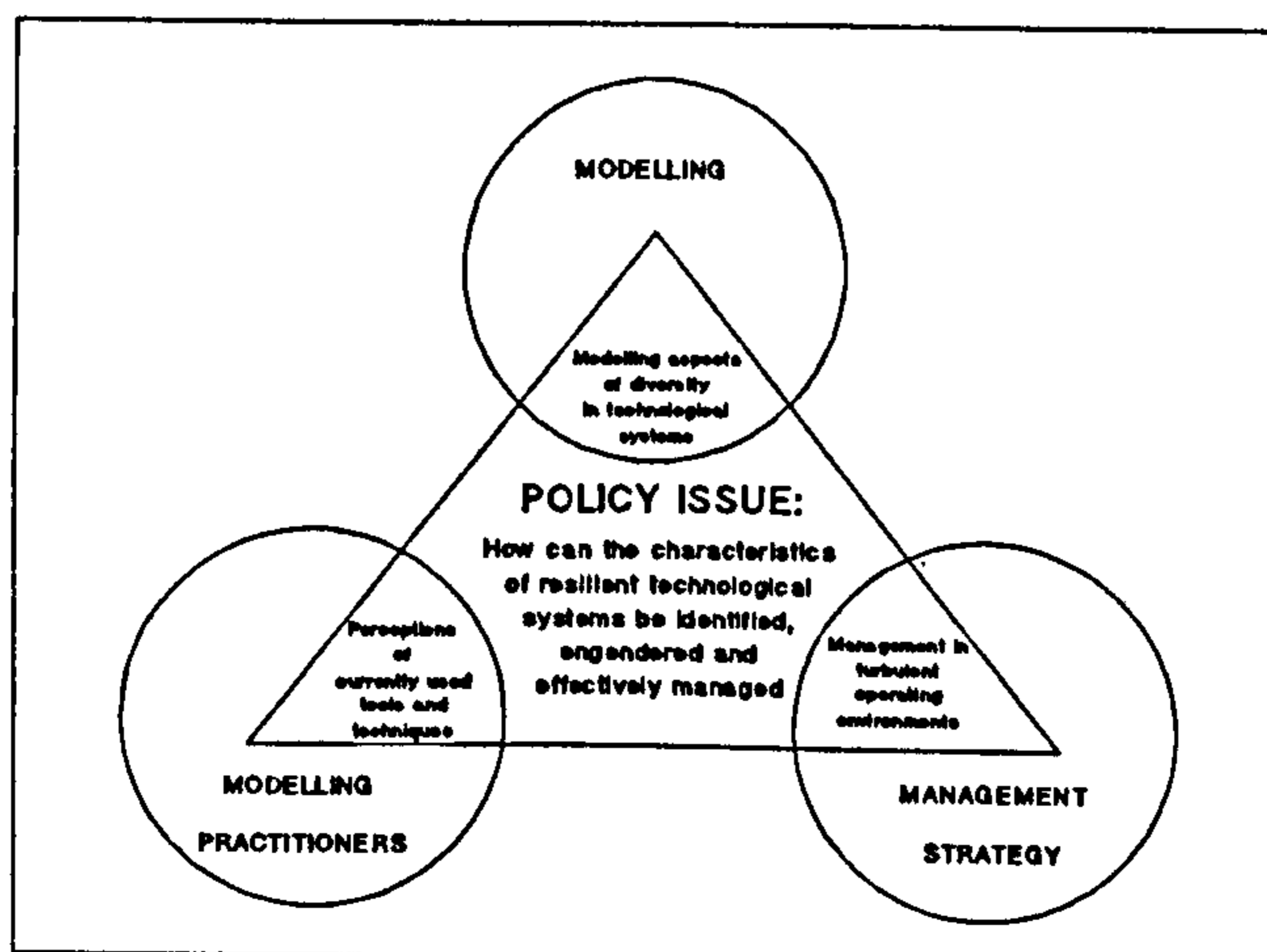
The primary research question is focused on a policy issue, articulated as follows;

Primary research question

'How can the characteristics of resilient technological systems be identified, engendered and effectively managed ?'

A detailed discussion of why this research question is of interest is provided below in Section 1.2. The study reported in the following chapters concerns the tools which organisations use to undertake planning and modelling in the area of technology investment and the application of these tools to long term planning. Consequently, the policy issue of long term infrastructure planning will be investigated from three perspectives; those of modelling, modelling practitioners, and management strategy. Figure 1.1 depicts these three elements of the study. Although there are more than three aspects of the policy issue which could be investigated, it is the concern of this study to highlight the associated planning issues. The three elements selected constitute key aspects of this issue.

Figure 1.1 Three perspectives on the core policy issue.



The interfaces between the policy issue and each of the three elements constitute foci for the research activities reported in Chapters 3-7. As a whole, the research effort provides evidence from more than one perspective and uses more than one set of investigatory techniques. Chapters 8, 9 and 10 will also make use of Figure 1.1 to frame the results and conclusions of the various research activities and synthesise the policy related comments.

The particular aspects of planning which motivates the research relate to issues of risk and uncertainty and the way in which these phenomena are addressed during the planning process. The outcomes of plans often achieve markedly less than was intended or become obsolete as their assumptions are overtaken by events. This occurs because we either fail to take account of all possible factors / influences, or are incorrect in our assumptions about the future behaviour of the target or related system. The management of the phenomena of risk and uncertainty is thereby associated with ineffective planning. Hence, the research activities commence with an investigation into the nature of risk and uncertainty and their influence on the organisational planning function. This results in a specific interpretation of the phenomena which is used to develop an approach to long term planning of technology infrastructures based on a clearer understanding of the role of resilience (Chapter 2).

The three research activities themselves address various elements of the problem area discussed above. The modelling activity (Chapters 3 & 4), seeks to examine the bounds of a specific class of formal simulation model in providing guidance on the decision issues raised above. These models are characterised by dynamic (non-linear and non-cyclic) cost functions, the representation of flexibility in the form of diversity, and decision algorithms with which to simulate plant investment and operational management decisions. Dynamic cost functions are used to simulate an uncertain capital and operating cost regime, whilst the attributes of diversity are captured by redundant capacity. It is then postulated that the application of planning tools based on ideas of resilience and flexibility will be of greater relevance under conditions of high environmental turbulence. Hence a survey of management under such conditions is undertaken (Chapter 5), focusing on approaches to dealing with uncertainty and the use of formal analysis tools. Finally, the attitudes of modelling practitioners towards their tools and their application constitutes the subject matter of the survey of U.K. Operational Research professionals (Chapters 6 and 7). Hence a linkage is made between formal analysis methods and the practitioners of formal analysis.

With regard to the remainder of this chapter, the following sub-section discusses some of the key terms and concepts used in the study and Section 1.2 discusses the nature of sustainability and its relevance to this study. Section 1.3 reviews the objectives of the thesis and derives three secondary research questions for use in the research activities whilst Section 1.4 reviews the thesis structure and content. Finally, Section 1.5 considers the rationale for adopting an interdisciplinary approach to analysing the primary research question.

1.1.2 Discussion of some key terms and phrases.

Finally in this opening section, some discussion of the way in which the various elements of the study are conceptualised is warranted. This will clarify the meaning of some key words and phrases which are used in the text.

The idea of 'system' has been adequately discussed elsewhere, perhaps still most accessibly in von Bertalanffy's writings (e.g. von Bertalanffy, 1968). Checkland (1981) argued that systems are difficult to define as absolute forms and that they should be treated as nominal forms, created for the purpose of exploration. Davies (1992) has questioned this position, clarifying the phenomenological nature of a system and making a case for a higher level of isomorphism between the concept of a 'system' and reality. Within the context of this study, a system is considered a convenient way of conceptualising multiple component assemblages of elements which we perceive in the world (System: '*complex whole, set of connected things or parts, organised body of material or immaterial things*' - Concise Oxford Dictionary, 4th Edition. 1951). A system is therefore a conceptual classification composed of various components which may or may not exhibit structure, interaction and purpose. The technological systems which form the focus of this study are so termed because their major components are technological in nature. However, it is the cost and performance attributes of these technological systems that are of particular interest. Hence, the concept of system is used specifically as a boundary with which to both describe and analyse configurations of technologies under varying operational conditions, and generally as a conceptual tool for structuring elements of the subject matter.

A second key concept used in this study is that of management's role being primarily one of planning and control. The term 'function' is defined as a '*special activity or purpose of a person or thing*' (Concise Oxford Dictionary). Using management as the object of the noun, the broad management function can be interpreted as the activities of management. Essentially, the role of management for the purposes of this research project is viewed as one of developing and selecting proposed courses of action (the planning function) and, once a course has been decided upon, directing the organisation in such a way as to achieve those ends (the control function). Hence, the use of 'planning and control' as a broad term to denote the management function

The characterisation of the management function in this way is common in the organisational science literature (e.g. as found in Koontz & O'Donnell, 1972). This study has a bias towards the planning aspects of the management function. A planning function is characterised by the use of formal processes and methods to derive intended courses of action for the organisation, or elements of it, to act upon. It constitutes a forum within which decision support activities and broader strategic aims are integrated in a decision making process. Members of the organisation (individuals who work towards organisational goals) are referred to as 'organisational actors' in the text.

A concept that is related to the management function is that of 'policy' or 'strategy'. The term 'strategy' initially entered the management literature to mean that which is

done to counteract the actions of a competitor. Policy was a term already in use, denoting a general plan or course of action. Today, the two terms are often indistinguishable (Steiner, 1979), and, following the example of much recent work, they are used as synonyms in this study. The terms are used to indicate a management process of plan formulation and implementation at a level of application which reflects broad organisational aims. This dual element interpretation of strategic management is both found in the literature (e.g. Byars, 1992), and reflects the role of management as one of planning and control as outlined above. Hence, in the context of this thesis, 'strategy' is taken to suggest '*actions or patterns of actions intended for the attainment of goals.*' (Swamidas & Newell, 1987).

The adoption of a systems theory approach to framing the issues involved results in the use of two further concepts which require some explanation; those of 'operating environment' and 'turbulence'. An organisation's 'operating environment' is taken to consist of those structures and activities which exist outside the bounds of the organisation itself. This is a necessarily fuzzy boundary. However, an operating environment comprises phenomena that the organisation is faced with and has little or no control over. Figure 2-1 (§ 2.2.1), may be found useful here as it includes an illustration of the organisation and its operating environment.

The behaviour of the operating environment is of interest in the context of this study due to its often unpredictable nature. The term used to denote this behaviour in the text is 'turbulence'. It should be noted that turbulence does not necessarily infer unpredictability and its dictionary definition merely refers to: '*Disturbed, in commotion*' (Concise Oxford Dictionary), suggesting movement and instability. However, it is assumed for the purposes of this study that significant elements of the organisation's operating environment will be unpredictable and 'turbulence' is used to describe such changes. This position is adopted for two reasons. Firstly, turbulence is a relative measure of change and to apply the term 'turbulent' to an environment which is unstable but predictable, would be a misnomer. Secondly, in the context of the study reported below, changing, unpredictable conditions typify the operating environments faced by technological infrastructures over extended time periods. Hence, the term 'turbulent operating environment', is used to denote a set of changing and unpredictable external phenomena encountered by an organisation (examples include interest rates, labour availability, raw material costs, environmental regulations etc.).

Finally, much is made (both in Chapter 2 and in Chapters 5-7) of the influence of a 'mechanistic' or 'rational/scientific' approach to problem solving. These terms are used to denote an approach which encourages disaggregation, quantification, and the viewing of a problem within a mechanical or clockwork-like framework. The meaning of 'rational' is often defined as '*the use of reason or logic*' (Concise Oxford Dictionary). These descriptors allow a great deal of latitude for interpretation, covering both objective and subjective processes. However, there has been a dominant interpretation of 'rational' which pervades the scientific and business communities, focused on the need to quantify and measure in order to plan and control.

It is difficult to provide a closer definition of this approach without straying into the areas of paradigms and the philosophy of science. However, the approach operates by classifying and identifying the system's components and the causal links or mechanisms that act between them (Allen, 1992). The important aspect of the approach from the perspective of this study is that it relies upon the identification of constant relationships and structures. Certain characteristics are typical of such an approach, and include the use of optimisation and mathematical proofs, simplification or standardisation of unstable or dynamic parameters, and a desire for predictive output. The critique of this approach which is developed in Chapter 2 is context specific and does not constitute a sweeping censure of the approach itself. What is being challenged is its pervasiveness in what may be inappropriate contexts.

1.2 Sustainable resource provision as a desirable objective.

As noted in Section 1.1.1, the Primary research question is concerned with issues of resilience in technological infrastructures. This section seeks to explain why such an issue is of interest as a research problem. The planning of long term technological infrastructure concerns the development of planning methods and implementation strategies designed to ensure consistency in technological system performance over changing operating conditions. Consistency of performance may relate to a number of aspects of the system such as product / service quantity, quality, reliability, cost and availability. Various characteristics of the system will influence its ability to achieve consistency. These include, the system's spatial configuration, the technological attributes of individual items of plant, and the interactions between specific technological attributes such as scale, cost functions, design life and the diversity of technologies being used.

Providing consistency of performance is a special case of the broader concept of sustainability. Sustainability is currently a popular characteristic for investigation across a range of disciplines. The relative nature of sustainability (Brown et al, 1987), has been expounded as a criticism of approaches to developing strategies focused on long term goals of sustainability. Although some features of sustainability are application and context specific, a common property across all uses is its relationship to a target utility measure. For example; sustainable agricultural systems aim to maintain the production of food, sustainable ecosystems endeavour to provide supporting habitats for various life forms etc. The scope and duration of sustainability is also context specific and there is much debate about pertinent time scales, boundaries, and relevant objective functions. Support for a view of sustainability which recognises these difficulties can be found in several areas of literature although by far the most relevant is that emanating from the field of ecological economics (See Common & Perrings, 1992, for an introduction).

It is important to bear in mind that sustainability of good or service provision is the key concept here rather than the sustainability of either the technological system itself or the investment strategy which is adopted. Changes in technologies and social priorities may, in time, necessitate major modifications to the configuration and operation of the system. Hence, sustainability of a single technology or technological

system would in fact serve to diminish the chances of achieving sustainable resource provision. Therefore, the concept of systems which can provide sustainable resource provision is closely associated with issues of technological change and socio-economic policy (ref. comments in Section 1.1.1 concerning the need to widen the perspective applied to infrastructure planning). There is little advantage to be gained from dictating either specific technologies (production or distribution) or operating regimes when the form and performance characteristics of future technologies are as yet unknown. A level of abstraction is therefore required in any useful definition of sustainable technological systems. This will allow temporal and contextual relevance to be given to the determinants of sustainability, allowing short and medium-term planning to be integrated with longer term issues.

It is clear that sustainability is both a relative and a complex issue and it has been suggested that a clear working definition may be problematic:

'Perhaps the concept of sustainability cannot be expressed in terms of a single objective function, but has to be treated as multidimensional ... This (evaluation) system might not be an intellectual process or methodology, but rather a social or political process that proceeds according to a set of ground rules that can be specified or agreed to in advance.' (Brooks, 1986)

It is possible to expand this proposition that a multidimensional objective function may be required into a view of sustainability as a hierarchy of objectives and attributes. For example, the key features of a sustainable food production system may include aspects of biodiversity, soil quality, water supply regimes, demand levels, farming techniques and quality limitation. Each of these issues will, in turn require analysis in regard of their own sustainability. (An expanded discussion of this hierarchical view of sustainability can be found in Section 2.10.1). Of perhaps greater importance however is the requirement that the goal of sustainability be itself sustainable. In other words, the development of a sustainable food production system is dependent upon the setting of a sustainable goal for food production. If such a sustainable goal is not established, the system will constantly be attempting to achieve impossible performance targets. The significance of this point is highlighted by the research conclusions (for example, see § 8.3.3)

With specific regard to the types of technological infrastructure being addressed in this study (water, gas, electricity etc.), the attribute of system resilience is desirable if consistency is to be achieved. Several types of resilience are addressed in the study, including cost stability, low total costs, and the management of technological infrastructures under turbulent operating conditions. Questions concerning the long term sustainability of other types of system (social, economic and biological) is a popular contemporary issue, attracting research interest from national and international sources. Investigating how resilient technological infrastructures can be identified and evolved is one element of this research effort and this thesis will, in part, draw a number of conclusions relating to this issue.

1.3 Objectives of the study - Identification of secondary research questions.

As indicated above, this thesis is concerned primarily with issues of planning technological systems. In order to provide a set of intentions with which the thesis' output can be compared, this section addresses the study objectives, developing a set of research questions from the issues summarised in the previous section. It also furnishes an overview of those research methods and techniques utilised during the project. This is achieved by presenting an abstract of the research activities and elaborating on the methodological and technique related aspects of each one.

Section 1.1 indicated that the key issue for consideration in this thesis concerns identifying the characteristics of resilient technological systems and researching how they can be effectively managed. It was also stated that planning failures in respect of technology planning are directly related to the effect of risk and uncertainty on various aspects of the planning process including the use of modelling techniques and decision analysis procedures. Resultant from an awareness of these issues, an introductory activity to the research effort should be to review the nature of risk and uncertainty, their influence on planning and modelling activities, and current approaches to representing the phenomena and addressing their undesired effects. This constitutes both an examination and critique of current thinking in the field of concern. Tools for the analysis of these issues include literature searches, associated reference material, and some theory development. Chapter 2 presents this part of the study.

Having provided some background to current approaches to handling uncertainty in technology planning, Chapter 2 goes on to broaden the concept of resilience introduced above by presenting a discussion of its main features. The objective of Chapter 2 is therefore twofold. Firstly, it aims to provide a backcloth to the research activities by clarifying the problems associated with current techniques for addressing risk and uncertainty. Secondly it illustrates the concepts to be used in the alternative approach which forms the focus of this work (that of promoting and managing resilience through diversity).

The three perspectives illustrated in Figure 1.1 then provide a series of secondary research questions which will be addressed by the three research activities reported in Chapters 3 to 7. The modelling activity (Chapters 3 and 4), seeks to investigate the potential for modelling resilience in technology systems. It addresses a subset of the problem, focusing on redundancy and cost variety as sources of diversity and taking a simulation approach to the modelling of total cost trends over long time horizons. The research question associated with this activity has an intentionally general character as very little research of this type has been previously carried out. It can be formulated as follows:

Secondary research question #1

'To what extent can the cost effects of a diversified technology base operating under turbulent conditions be effectively modelled and if so, what are the major aspects of diversity that are responsible for any increase in utility.'

The survey of modellers and decision makers operating in a turbulent environment (Chapter 5), seeks to assess the development of strategies in a situation where rational approaches to planning may be ineffective.

Secondary research question #2

'What management planning and control strategies are adopted by modellers and managers operating in a turbulent environment.'

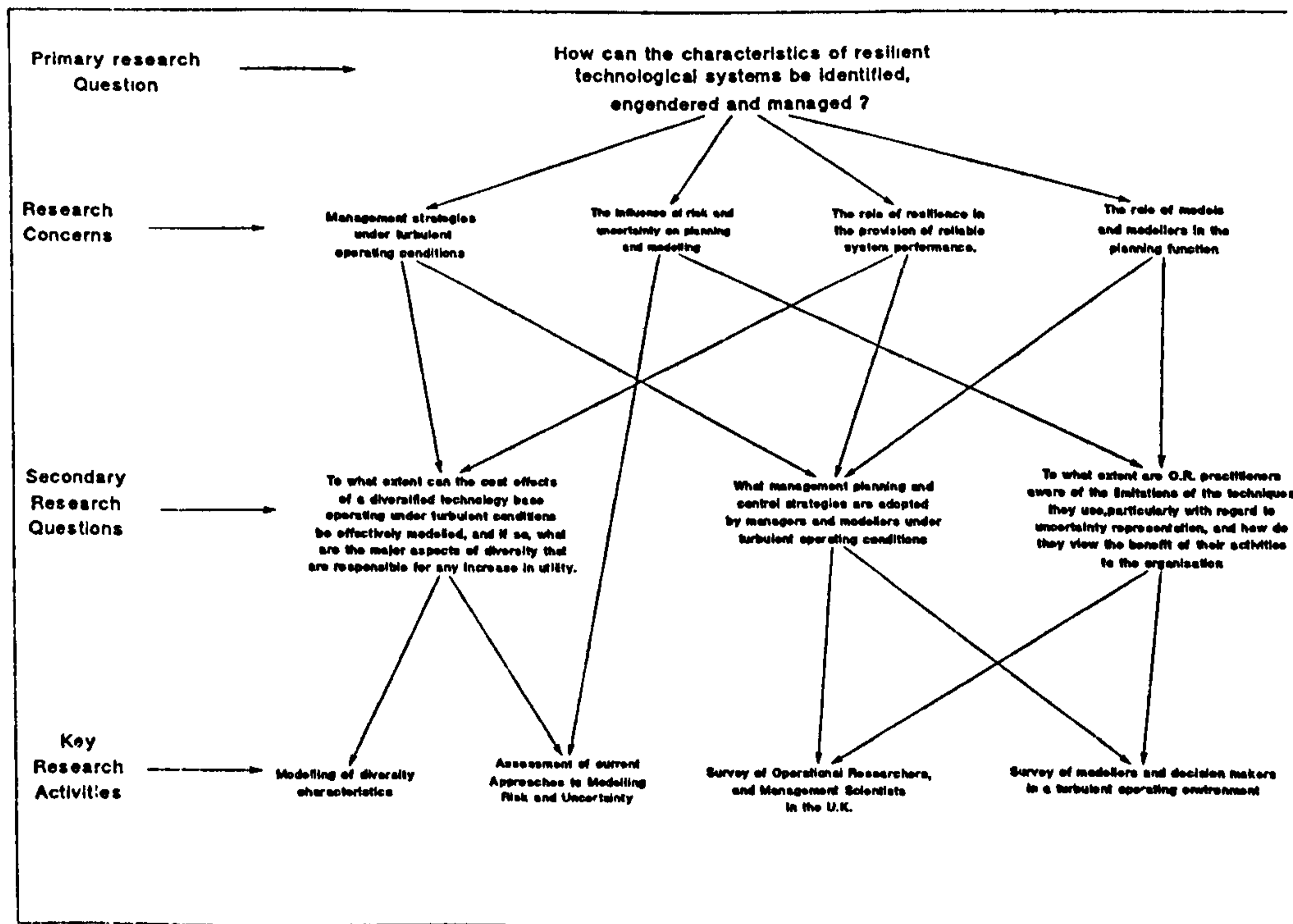
Finally, the survey of O.R. practitioners in the U.K. (Chapters 6 and 7), has a more closely defined objective and concentrates on identifying O.R. professionals' use and perceptions of the tools and techniques they utilise.

Secondary research question #3

'To what extent are O.R. practitioners aware of the limitations of the techniques they use, particularly with regard to uncertainty representation, and how do they view the benefit of their activities to the organisation.'

Each research activity and its associated findings are reported in detail in the relevant Chapters. Additional information such as computer code listings and questionnaire / interview templates are located in Appendices 1-3 at the back of the thesis. Chapters 8 and 9 address the emergent policy and methodological issues raised by the research activities. Finally, Chapter 10 returns to the framework provided by Figure 1.1, allowing the interdisciplinary nature of the study to be exploited so as to provide both single perspective and integrated, policy oriented, conclusions and recommendations. Figure 1.2 (below), presenting a mapping of the research questions onto both the research concerns and individual research activities.

Figure 1.2 Mapping of research questions, research concerns, and research activities.



1.4 Thesis structure and review of main arguments.

The purpose of this section is to confer some structure on the thesis by presenting a discussion of the various elements and providing a framework within which its contents can be referenced. It also anticipates the main arguments presented in the following chapters so as to give some indication of the main themes and issues to be discussed.

With regard to the various arguments and themes which run through the study, the interdisciplinary nature of the work tends to result in diffusion of the main arguments. It is therefore pertinent at this point to briefly summarise the main issues which are to be found in the study, and provide some reference to their positioning within the thesis (Numbers in parentheses represent the subsections within which the various arguments are located). As mentioned above, this initial chapter is concerned with the background to the study, procedural aspects of the thesis' structure and content, and a discussion of some methodological issues. In addition to a discussion of the relevance of an interdisciplinary approach (§ 1.5), the problem of identifying technological configurations which promote stable product supply is reviewed and the relevance of viewing the problem as a special case of sustainability is presented (§ 1.2). The influence of risk and uncertainty is introduced as the major cause of planning failure and the intention to use this issue as a starting point for the study is stated.

Chapter 2 reviews the role of both modelling and modellers (§ 2.2) and develops a critique of the influence of risk and uncertainty on both these elements of the organisation and the planning function in general (§ 2.3-2.5). The critique highlights the influence of a mechanistic interpretation on the development of many methods used to address uncertainty and two propositions are submitted. Firstly, a conceptual framework is proposed that aids an understanding of the level of control available to the organisation when operating in an environment with varying levels of uncertainty associated with different aspects of the organisation's activities. (§ 2.6). This assessment of 'management sovereignty' distinguishes between control, influence and impotence as levels of management authority over organisational activities. Secondly, the usefulness of evolutionary and ecological analogies as a framework for the development of alternative approaches to handling uncertainty is introduced as an alternative to the mechanistic approach (§ 2.7). The main attributes of resilience, flexibility and other related terms are outlined (§ 2.8), and a tentative taxonomy of their application within a technology investment framework is proposed (§ 2.9).

Chapter 3 constitutes the first of two chapters reporting the modelling activity. It opens with some comments on current approaches to modelling uncertainty and resilience in technological systems and specifically reviews developments in relation to the Electricity Supply Industry (§ 3.2). In addition, and as background to the modelling activities themselves, a review of modelling techniques used in evolutionary theory is presented (§ 3.2.4). The background to and execution of, a spreadsheet based modelling activity which was undertaken as part of the research effort is then presented (§ 3.3). Taking the critique developed in Chapter 2 as a starting point, a number of aims for the modelling process are defined. Concentrating upon the issues of technology selection and sequential investment decisions, the

model examines the behaviour of a diversified technology base with regard to temporal, cost and scale variables. An advanced version of the model, written in the 'C' programming language is described (§ 3.4) and details of the included variables and relationships provided. Graphical output from the model is combined with textual information about the control parameters for each model run. The structure of the models evolved over the research period to reflect the changing requirements of the study and diagrams showing the broad framework and activities of each model are available in the appendices. Results from these initial modelling activities illustrate the benefits of diversity (as represented by redundant capacity which possesses a different cost structure) under limited circumstances. The sensitivity of this advantage to changes in the relative movements of the cost functions used is also identified.

Chapter 4 takes the modelling activity reported in Chapter 3 a stage further and reports the development of a simulation model designed to analyse the influence of diversity on the long term cost performance of a technological system. An explanation and discussion of the technological characteristics selected for representation in the model is presented (§ 4.2), and details of the simulation results illustrated (§ 4.3). Details of the problems associated with model development are addressed at length including the issue of providing a simple, reliable measure of environmental change. In particular, the issue of multiple solutions is discussed (§ 4.4). The positive results from this element of the modelling activity relate to the use of the model to investigate issues of cost stability (§ 4.5), and here it is demonstrated that several types of diversity have a beneficial effect on the stability of costs in a multi-plant technological system.

In summary, the modelling activities contribute to the study in two ways. Firstly, they highlight several important obstacles to using this type of simulation model for the analysis of diversity and turbulent operating environments (methodological findings). Secondly, they provide an indication that under certain circumstances, there are total system cost benefits to be gained from diversified technological systems over single technology systems (policy findings).

The second research activity is reported in Chapter 5 where the design and execution of a survey of modellers and decision makers carried out in Israel is presented. The aim of this research activity is to expose aspects of management and planning strategies that are adopted by organisations operating in an environment where strategic planning based on the 'predict and prepare' approach would be ineffective. This predict and prepare approach is adopted as a direct result of the mechanistic approach to analysing risk and uncertainty highlighted in Chapter 2. Such an approach, and its consequences, are well reviewed by Ackoff (1983). It is proposed that alternative strategies will both emphasise flexibility and be human centred in nature (§ 5.1). Details of the relative level of environmental turbulence in Israel are provided (§ 5.2), and a discussion of the survey methodology and design is presented (§ 5.3). Results from the survey (§ 5.4) lend support to Lindblom's propositions concerning the 'muddling through' view of management planning and control. The main issues of concern to managers tend to lie outside their sphere of influence and there is evidence for a characteristic management style based on informal information

gathering and a reliance on the attributes of the organisation's human resources to deal with environmental changes (§ 5.5).

The third and final research activity, concerning the assessment of attitudes to modelling amongst Management Science professionals, is reported in Chapters 6 and 7. Chapter 6 provides a discussion of the background to the study (§ 6.2) and discusses some of the methodological problems encountered during the survey (§ 6.3). This chapter finishes with an outline of the data analysis methodology used (§ 6.4). A copy of the questionnaire template and details of a collaborative link with the Operational Research Society of the UK are provided in an Appendix. Chapter 7 is concerned with the interpretation and analysis of the survey results (§ 7.2), and generates a number of comments concerning the awareness of O.R. practitioners with regard to the capabilities and role of the models they utilise. In addition conclusions are drawn on issues of professionalism and the dominance of a rational / scientific approach in the formulation and application of models (§ 7.3).

The pertinent findings of this element of the research project relate to the awareness of O.R. practitioners in the U.K. about the limitations of the tools and techniques which they use. Furthermore, there is a strong desire to ensure the communication of these limitations to decision makers. Finally, there is a suggestion in the survey data that O.R. practitioners see their profession as being primarily concerned with 'rational' and 'scientific' contributions to decision support.

Focusing on the main issue of technology planning, the study's findings are shown to make a contribution in two areas. Firstly, a set of comments concerning the role of diversity and resilience as elements of an alternative strategy towards addressing turbulent operating environments are derived from the main body of the thesis. These are concerned with identifying potential strategies based on diversity and flexibility and which may prove both achievable and beneficial. Secondly, an agenda for identifying some methodological bounds to these types of strategies can be identified. This theme is concerned with the relationships between models, modellers and the comparative contribution of various elements of the planning function to determining strategies for managing resilience. Accordingly, Chapters 8 and 9 address the policy related and methodological aspects of the research work respectively, and draw together relevant research findings in an integrated assessment of each aspect.

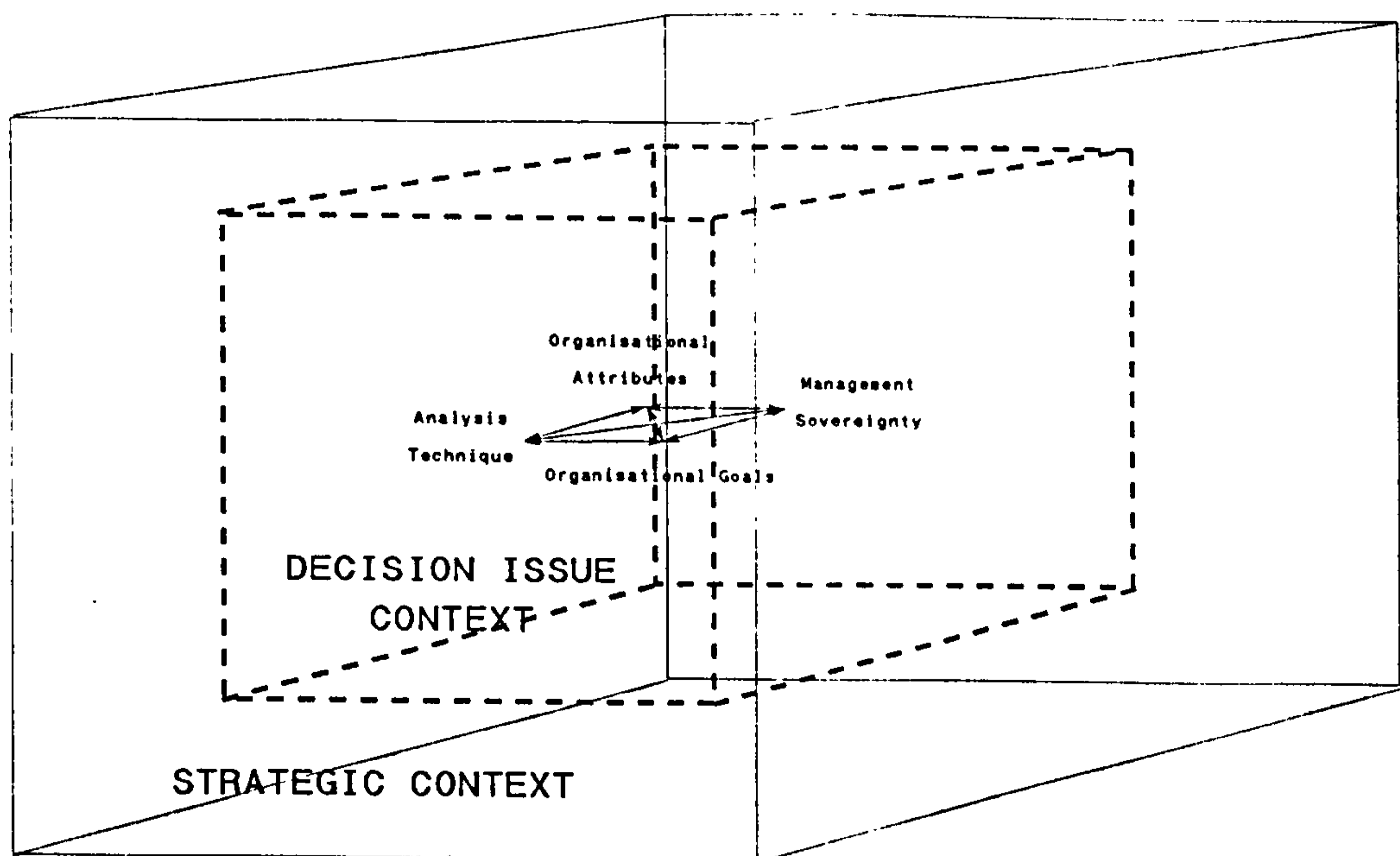
After revising the research aims and restating the primary and secondary research questions (§ 8.1.1), Chapter 8 goes on to consider the policy related aspects of the research findings. These include a discussion of the potential for modelling resilience in technological systems (§ 8.2), and the implications of the research for the management function and criteria for project selection (§ 8.3).

Chapter 9 addresses methodological issues such as the problems of modelling diversity in technological systems (§ 9.2) and difficulties facing management in planning for diversity (§ 9.3). Finally in this chapter, the role of Operational Research practitioners and their perceptions is discussed in the context of method development and use (§ 9.4).

The final chapter of the thesis, Chapter 10, is concerned with integrating the thesis' findings and clarifying the research findings. Each of the secondary research questions is addressed in turn using relevant information from the research activities (§ 10.2.1 - 10.2.3). An interdisciplinary framework within which the primary research question can be addressed is outlined and the question itself is disaggregated into three sections for assessment. Following an appreciation of the implications of the study for further research (§ 10.4), some practitioner focused comments are advanced (§ 10.5) and the thesis contribution revised.

Consideration of the research findings allows a conceptual framework to be developed that matches certain organisational attributes, organisational goals, selection of analysis techniques and levels of management sovereignty within a specific decision issue and strategic context. Figure 1.2 (below) depicts the general form of this framework. It will be shown how the various research activities contribute to the development of the framework and how it can be used to aid discussion of the salient issues emergent from the research activities.

Figure 1.3 Conceptual framework for assessing the use of organisational attributes, organisational goals, analysis techniques and levels of management sovereignty within a specific decision issue and strategic context.



1.5 An interdisciplinary perspective on policy level research.

Section 1.1 reviewed the main issues which form the basis for the research activities presented in this thesis. This Section identifies the role of interdisciplinary analyses in the context of assessments of policy and strategy, and discusses the relevance of an interdisciplinary approach to studies of the type presented here. As a preamble to these discussions the following paragraph reviews the case for assessing more than one perspective on any single issue.

It is said that Gottfried Leibnitz (1646-1716) was the last man to have known everything. The increasing breadth and depth of scientific knowledge has resulted in the emergence of a myriad of disciplines or branches of learning (economics, statistics, physics etc.), each one requiring many years study to reach the forefront of research. Policy problems (in this context those concerned with the general approach or plan of a government or other large organisation), often cut across disciplinary boundaries, taking input from several fields and requiring synthesis and integration in order to be of any applicable use. In 1968 the economist Kenneth Boulding commented that *'unless the output of most specialities becomes the input of others, knowledge breaks up into a mere aggregation of isolated entities and ceases to be a single body.'* (Boulding, 1968). In the case of policy studies such a warning is doubly apt. Knowledge can only be usefully applied within a particular context, the characteristics of which form an additional problem domain for those wishing to appropriate the potential benefits of knowledge application.

1.5.1 The relevance of an interdisciplinary approach to studies which contribute to policy formulation.

The analysis of policy and strategy issues is a relatively new field of research and is still struggling to find both a common empirical approach and a framework for applying research results (Bozeman, 1986). Schnieder et al's comment that *'Aside from some base consensus that the policy field is multidisciplinary and problem orientated, there is little agreement about what policy enquiry is or should be.'* (Schneider et al, 1982), still holds true today. A major problem for policy research is the lack of synthesis which policy relevant analyses exhibit Hedge & Mok (1987).

The identification of a suitable inquiry framework for policy analysis is dominated by the need to provide the policy formulation process with both tools for investigating policy options and an appreciation of the breadth of influence which any decision may have. Several recent studies have concluded that traditional scientific models have never applied very well to policy analysis (Dunn, 1981; Cleveland, 1988). Other writers have questioned these approaches because of their emphasis on quantification and rejection of values as determinants of action (Tait, 1988). The significance of these comments at this point is the emphasis it places on atomism and disaggregation. This is a methodology of 'divide and conquer', where both physical and conceptual phenomena are broken down into their constituent parts and the whole is considered as a complex mechanism. In his review of paradigms in policy making, Daneke (1989) states that:

'A significant paradigmatic shift is severely hampered by extreme disciplinary isolationism on the one hand and the pervasive imperialism of neo-classical economics on the other.'

Referencing the pioneering work of Holling (1978), Daneke calls for *'modest conceptual developments, seeking new applications for notions such as resiliency, adaptive learning, and other institutional dynamics.'* The first of these issues

(resiliency), is directly addressed by this thesis whilst the second (adaptive learning), constitutes an element of the research findings reported in the final chapters.

Increasingly, in the spheres of environmental, ecological, economic and social policy analysis, the failure to recognise the inter-connectedness of diverse system types is identified as a barrier to successful policy and strategy implementation. It is the intention of this thesis to adopt an interdisciplinary approach to the issues outlined in Section 1.1.1 Supporting reasons for such a mode of analysis can be narrowed down to three main points:

- (i) Technology selection, as a process, is an incremental procedure involving organisational, individual, technological/engineering, financial and other elements Hence, an overall assessment of the problems associated with technology selection is problematic without the use of a diverse range of techniques.
- (ii) Determinants of the efficacy of investment planning as both a methodology and decision support procedure are diverse in nature. Thus, a broad appreciation of the possible sources of planning failure is necessary.
- (iii) The fundamental nature of the planning function and the influences of risk, uncertainty and surprise, expose both perceptual and rational aspects of the decision making process (See Chapter 2).

1.5.2 How interdisciplinary research differs from other cross disciplinary studies.

Rossini & Porter (1984), propose a three way definition of cross-disciplinary studies. They see 'Multidisciplinary Research' as comprising a number of independently performed studies with external co-ordination through appropriate editorial linkages. 'Transdisciplinary Research'. is considered to include the development of an overarching paradigm which encompasses a number of disciplines. Finally, 'Interdisciplinary Research' falls between the two previous approaches; components being linked internally and substantively without being subsumed under a supradisciplinary paradigm. A distinction is made in this work between multidisciplinary and interdisciplinary inquiry and the following distinction is seen to be of help in describing the work presented in the following chapters.

Multi-disciplinary - referring to research projects which either:

- a) Take the output of single discipline and provide a 'post hoc' framework for interpreting the results. or
- b) Comprise a co-ordinated attempt to investigate several areas of a single issue without the prior design of any integrative framework for assessment.

Interdisciplinary - referring to research which is designed to both provide information on more than one aspect of a problem, *and* integrate the results in a way which assists policy and strategy analysis.

Interdisciplinary research is an emerging and still evolving method of enquiry and its application to the primary research question can be seen as a novel approach to investigating the policy and strategic aspects of technology planning. Whilst nature does not come in a disciplinary form (Ackoff & Emery, 1972), this does not negate the contribution of single discipline studies. Applying selected research methods and techniques to well bounded problems enables both a theoretically and a practically robust analysis to be conducted. This is typically the case where the system of interest is either simplified for analysis purposes or possesses characteristics which allow an approach based on issue disaggregation to be adopted. Problems arise however when qualitatively different types of system are under investigation such as those where deterministic (predictable through cause-effect relationships), and non deterministic systems are combined to form a focus of concern.

An interdisciplinary research method constitutes a process for the analysis of disparate sources and types of information. The objectives of the contributions are to inform the decision making process as to the nature and context of key elements of the decision problem. Accordingly, interdisciplinary research is faced with a quasi-political agenda. Problem formulation and information interpretation become formalised within a framework which is ostensibly neutral or 'scientific' but which directly addresses issues of multiple criteria and implementation. This dimension to policy and strategy analysis is raised by Rosenhead (1992) and its recognition is a direct result of the reassessment of the role of Operations Research / Management Science (O.R / M.S) (see § 2.2.2 for a more detailed discussion of this reappraisal).

An interdisciplinary agenda acts in opposition to the political and institutional ideologies which dominate the decision making process. Historically, what has tended to happen is that decision makers have become selective about which policy/strategy assessments they access, thereby re-establishing ideological hegemony over the decision making process. However, this fact does not diminish the need for research which addresses policy related issues, nor does it detract from the potential contribution of such studies.

The potential benefits from the application of interdisciplinary studies are of three distinct forms; contributions to theory, development of improved methodology, and support for decision analysis techniques. By developing an integrated analysis of issues with multiple and inter-related aspects, interdisciplinary research can expose the pertinent system properties and dependencies. In particular, it can help in the identification of qualitative system changes and highlight the nature of the limits of quantification in qualitative systems. Perhaps its most influential contributions are in the provision of a policy perspective on the bounds of single discipline analyses and the development of a formal methodology within which trade offs, and competing perspectives can be analysed.

By applying more than one method to the analysis of a problem, interdisciplinary analysis formally introduces the complexity of the real world into the decision making process. Two features of interdisciplinary analysis serve to emphasise this point. Firstly, the search for optimal solutions has been a characteristic of problem analysis methodologies since the emergence of the empirical scientific tradition in the Seventeenth Century. Optimal solutions simply do not exist for a whole range of problem types (or if they do, the definition of optimal used is so broad as to make the use of an alternative term desirable). An interdisciplinary approach, by its very nature, shifts the focus away from ideal solutions towards alternative criteria such as consensus, achievability and resilience. Secondly, involvement in the interdisciplinary analysis processes engenders an appreciation of alternative perspectives. This serves to promote an investigative / exploratory element into the analysis of decision issues and encourages the development of response options rather than problem solutions.

In summary, the study described below is intended to provide some indication not just of what is and should be done, but also of how it is and should be done. Several contributions in the field of Operations Research have highlighted the need for a broader assessment of modelling and its application to management problems (e.g. Stainton, 1979). By adopting an interdisciplinary approach to the primary research issue it is intended to provide both a methodological and application oriented contribution to the field.

1.6 Summary

The foregoing sections have outlined the major elements of this thesis, including a discussion of the relevance of an interdisciplinary approach to problem solving at the policy level.. Given the central concern of assessing technological configurations which provide for sustainable resource provision, there are three foci of research for the thesis as described above. Firstly, there is the problem of identifying suitable models with which to analyse the technologies concerned. Secondly, there is a need to assess the attitude of professional modellers to the tools and techniques they currently utilise. Finally, an understanding of potential strategies for operating under turbulent conditions is required to assist in the isolation of desirable attributes and characteristics. The contributory themes of the thesis can therefore be posited as a tripartite approach to technology planning, focusing on desirable attributes for sustainable goods and services provision.

Chapter 1 has described the research problem and its motivations, discussed the method of enquiry, and reviewed the research activities themselves. This provides a background for the following chapter, which addresses the nature of the planning process and the contribution made by models, modellers, risk and uncertainty. The adoption of an ecological analogy with which to derive strategies address uncertainty is introduced and the role of attributes such as diversity, flexibility and resilience is discussed.

CHAPTER 2

PLANNING TECHNOLOGICAL SYSTEMS: THE INFLUENCE OF UNCERTAINTY AND THE USE OF EVOLUTIONARY ANALOGIES AS A FRAMEWORK FOR ANALYSIS

2.1 Introduction

Having provided a template in the previous chapter depicting the motivations, aims and intents of this thesis, Chapter 2 addresses in more detail the fundamental concerns of the work. The following sections outline the role of modelling and modellers' in the organisation and provide a critique of current approaches to representing and assessing risk and uncertainty as part of the planning function. Where possible, studies which are focused on technological issues are reviewed although a large part of the literature in this field is general and relates to broader organisational concerns. However, Chapter 1 highlighted the interdisciplinary nature of this study and the literature and issues reviewed provide background material for both the modelling and survey work reported in Chapters 3-7.

A discussion of modelling, modellers and their role in planning procedures is presented in Section 2.2. Section 2.3 assesses the nature of risk and uncertainty, whilst Sections 2.4 and 2.5 go on to develop a critique of current approaches to risk and uncertainty representation. This critique leads to a policy oriented interpretation of the nature of risk and uncertainty (§ 2.6), and an introduction to the use of evolutionary analogies (including resilience) as useful tools for developing strategies which address risk and uncertainty (§ 2.7). Section 2.8 investigates the nature of resilience and its contributory elements and Section 2.9 goes on to apply the concept of resilience to technological systems.

2.2 Formal assessment and the role of models and modellers.

Reasoned afore-thought is one of our greatest advantages over other living entities. It allows us to formulate, test and consider our actions prior to their execution. Such conceptual simulation utilises both information from our past experiences and propositions about expected conditions. This '*process of human forethought and action based upon that thought*' (Chadwick, 1978), provides opportunities to influence our own and others' futures. As such, it is a positive contribution to social goal seeking activities. Planning can be viewed as the design and implementation of a desired future for the system. It has been characterised as a process which seeks to '*cause present changes of state in accordance with anticipated future states of the system of interest.*' (Rosen, 1974). Key problem areas for those engaged in such activities (planners), arise at both theoretical and practitioner levels.

At the theoretical level it is often difficult to dissociate planning from analysis and decision making. Whilst the boundaries between all three undertakings are unclear,

they require understanding and clarification for the purposes of subsequent discussions. The following explanations serve to indicate the usage of these terms in the forthcoming text.

(i) *Decision making* refers to the practice of considering an information set, and resolving competing criteria so as to arrive at a conclusion for action. It can be isolated (single decision event) or sequential (multiple events), and focused on an individual or group of individuals. A decision making process comprises a series of formal or informal activities designed to support and inform a decision event.

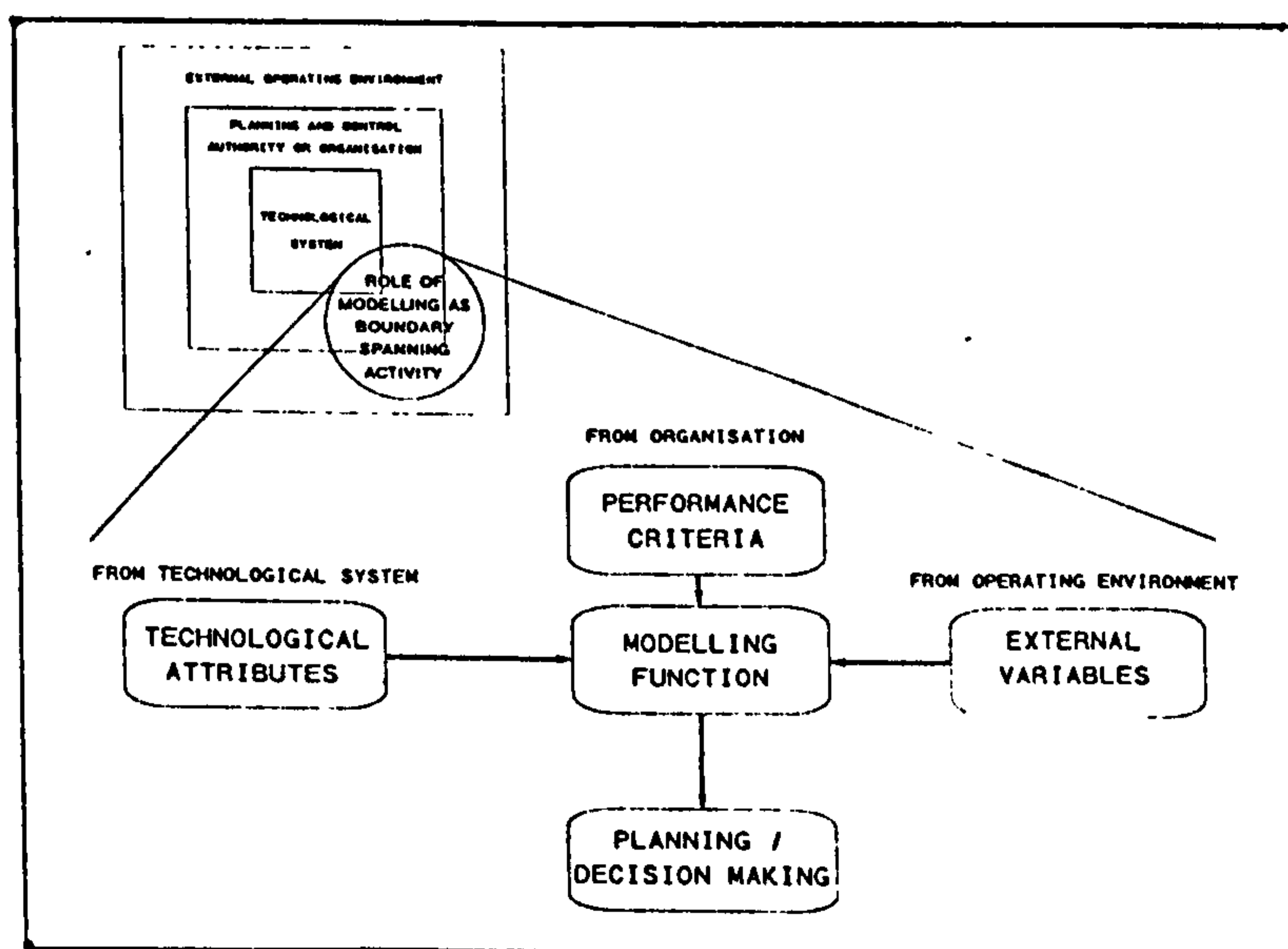
(ii) *Analysis* relates to a formal or informal process of investigation and assessment relating to a problem or situation. It involves an examination of the whole or constituent parts of a problem, and constitutes an input to the decision making process.

(iii) *Planning* fuses the contributions of decision making and analysis within a framework that assesses the ramifications of intended actions or activities. It constitutes an intention to act and ranges from purely mental operations to the use of complex representational systems, calculating aids, and rigid procedural frameworks.

2.2.1 Models and modelling as elements of the planning function

A simple interpretation of the role of models is depicted in Figure 2.1 The technological system can be seen embedded in the organisation responsible for planning and control which in turn is placed within an operating environment of external influences. Here, modelling is depicted as a boundary spanning activity, taking information from the technological system, the organisation and the operating environment, and providing input to the planning or decision support function.

Figure 2.1 Modelling as a boundary spanning activity.



One of the main characteristics of the planning function, is the use of models (Spencer, 1962). Models are essentially abstracted representations of perceived phenomena. The role of modelling is to facilitate the translation of the circumstances being studied into a more accessible, or more easily controlled and measured form (Haggett, 1981). As an analysis tool, models are ubiquitous; providing perhaps our only means of simplifying the complexity of the real world. Being dependent upon subjective formulation, models are thereby also relative. The classification of different types of models has attracted much thought and there are presently a number of discipline specific classifications. Most of these are built upon the work of Rosenbleuth & Wiener (1945) who described two broad categories;

1. Material models which comprise the representation of a complex system by one that is assumed to have similar properties to those of the original.
2. Formal models which are usually symbolic assertions in logical terms of an idealised situation which shares the structural properties of the original system.

Modifications to this typology have come from Churchman et al (1957) who bifurcated the material category into 'iconic' and analogue' models, and from Mihram & Mihram (1974) who proposed a three-way classification of material, literal, and hybrid. Iconic, analogue or symbolic models can be utilised to provide representations of real world or imaginary situations or relationships. The use of analogues as models in the planning process has been described as the use of one set of properties to represent some other set in the real world (Ackoff, 1962).

Technology Assessment and Investment Planning use models extensively within a management support role to aid problem formulation and solution (Willmer & Islei, 1986; Baker & Finizza, 1990). The modelling of technological, organisational, social, economic and financial systems is commonplace, resulting in a rich body of theory and literature from which to draw methodologies and techniques for use.

A major source of criticism concerning the formulation and use of large scale economic and socio-economic of models, has focused on the '*dearth of established quantitative theory upon which to base a complex socio-physical model*' (Cole, 1974). There was a wide ranging debate at the time this comment was made, focusing on both the 'Limits to Growth' model prepared for the World Bank (Meadows et al, 1972), and the studies carried out by the Science Policy Research Unit at the University of Sussex (An overview of these issues is provided in a special issue of 'Futures' -Volume 5. Number 1. February 1973.) However, on a positive note, Cole sees many modelling activities as being able to '*explore opportunities for social, cultural and economic development and anticipate the dangers in achieving desired futures.*' The relevance of these comments to this study will be seen in the concluding chapters.

Models play a number of roles in the planning function. These can be characterised as either 'conceptual' or 'formal' in nature. For the purposes of the ensuing discussion, the following distinction is drawn. Conceptual models are those which are held by individuals as a direct result of their perception, experience etc. Formal models are

those which are communicated by individuals in a representative format (paper, verbal etc.), to others. Consequently there emerges a complex web of interpretation and representation linking conceptual and formal models which of itself is a fascinating subject for debate. Functionally however, modelling achieves two elemental tasks: Simplification and structuring of the real world.

Simplification is necessary in order to achieve a manageable representation of a real world situation involving physical or conceptual attributes. It is required to ensure that manipulation of the resultant system representation is feasible. Hence scale, format and material changes may be involved. Simplification also enhances the extent to which the model can be articulated although in this context the level of simplification can be matched to the relevant audience and/or objective. The task of structuring is accomplished by determining the relationships (spatial, magnitudinal, qualitative, quantitative etc.) between specific elements of the system. Hence, cause/effect, influence, and physical patterns are exposed and a framework within which the model can be bounded is defined.

Both simplification and structuring processes influence the role of models in the planning function. The former acts as an invitation for analysts to decompose not only the system being modelled but also the manipulative tools available for intervening in the system as part of the control process. Furthermore, decisions about simplification and structuring empowers modellers and analysts as interpreters of the system, making them the gatekeepers of the applied methodologies.

As a tool for application to problem solving and in particular in support of decision making, a model can fulfil several functions:

- (i) Investigative / exploratory - Identifying and examining the salient features of the system.
- (ii) As an agenda setter or issue raiser.
- (iii) Recording the magnitudes and rates of change in key system variables (Historical).
- (iv) Simulating the effect of intervention. (N.B. The difference between simulation and prediction is purely a function of the perceived level of 'fit' between the model and the real world.)
- (v) Analysing the extrapolated behaviour of the system.
- (vi) Presentation of information.

Whether a model is used for predictive or illustrative purposes is not primarily a function of the type or form of model involved. It is rather a result of the user's attitude to the ability of the model to be predictive and is therefore also dependent upon the user's confidence in the model. Hence the issues of model validation,

perceptions of temporal relationships, and model belief emerge as influential factors in model utilisation.

It may be assumed that the value of a model is in direct proportion to its ability to reflect the real world. This is not true, but there are qualitative distinctions to be drawn between a reflection which precisely mirrors the real world and one which allows understanding and appreciation without being particularly detailed or accurate. (This perspective is most relevant when one considers the *objective* of a model). Model validation can therefore assume two forms; comparison with the real world, and comparison with the goal of the modelling activity. Simply put; the model's usefulness is directly attributable to the relationships between the reasons for modelling, the model type, and the expectations of the individuals engaged in the modelling process.

2.2.2 The role of modellers in the planning function.

Despite the key role played by O.R./M.S professionals in formalising the relationships between the activities of an organisation and its operating environment, there has been little work done on the attitudes of O.R./M.S. practitioners towards their own activities. The only major element of research in this area has been the internal debate within the O.R. profession concerning the proper execution of the O.R. function. There are two possible conditions which may explain the lack of interest in the O.R. function in general management circles.

1. Other organisational actors are unaware of the full implications of allowing a relatively small group of individuals to interpret and encapsulate the organisations activities in formal models.
2. Other organisational actors are aware of O.R. practitioner's role but act to repress their contribution and make it subservient to other aspects of decision making.

The success of any formal model was identified in the previous section as being a function of either comparison with the real world or comparison with the goal of the modelling activity. A shared conception of model validity is therefore necessary if decision makers and modellers are to operate as part of an integrated whole. If a situation exists where modellers' conceptions of their model's relevance and use is incongruous with decision makers' conceptions, there is the potential for misunderstanding and competing vectors of effort.

Modellers fulfil a number of functions within the organisation although their roles are not necessarily identical across positions and job descriptions. Amongst their activities however, most are engaged in the following:

1. Interpretation of problems identified by senior management.
2. Identification of relevant solution methodologies / techniques.

3. Interpretation, simplification and structuring of organisationally relevant systems within formal models of the problem.
4. Investigation of possible processes / configurations to enable problem solution.
5. Reporting of 1-4 to line managers or board level executives.

Through their activities, modellers act as a filter between the organisation's environment and its planning and control functions.

By using models and modelling techniques, the planning process exploits event and status simulation methods in order to assess the efficacy of various planning options. However, as outlined in Chapter 1, the phenomena of risk and uncertainty serve to reduce the confidence which planners can place in their blueprints for the future. The following two sections examine the nature of these phenomena and develop a critique of their representation in formal planning activities.

2.3 The nature of risk and uncertainty and their influence on planning.

Perhaps the first paper to specifically link an appreciation of risk and uncertainty with the planning process highlighted the role of uncertainty in planning thus:

"Terms like 'decision making', 'planning', and 'control' have become standard words with fairly standard meanings and implications. Once we recognise the existence of uncertainty, however, these words and the concept of management as a whole take on a new meaning and significance in a manner that is not readily appreciated by many writers." (Spencer 1962)

Whilst research into decision making, planning and control have developed into strong single discipline fields since Spencer remarked on them, the significance of his comments has remained largely unrecognised. In particular, uncertainty has been viewed as one problem to be solved by the planning function. Problems of risk and uncertainty have subsequently been approached in a way which reflects discipline specific strengths and weaknesses.

Two distinctions are required when dealing with risk and uncertainty as phenomena and these can be viewed as being definition based and perception based respectively. The first of these distinctions relates to the difference between risk and uncertainty as theoretical constructs i.e. their grammatical distinction. Knight (1921) proposed that risk referred to situations where the probabilities of outcomes are known or can be allocated, whilst uncertainty referred only to the array of possible outcomes and not their probabilities. Spencer expanded Knight's analysis and in effect initiated a series of investigations into both the nature of risk and uncertainty and their role in industry and commerce. In his concluding comments Spencer remarked that in the absence of

uncertainty, the co-ordination role of management would become superfluous in all but the initial phases of a project. Whilst adopting a simplified view of the management function this comment highlights the fundamental and omnipresent role which uncertainty plays in organisational control. Fisher (1971) endorses Knight's view and emphasises the difference between risk and uncertainty as being as that between known and unknown probability distributions.

An important aspect of this first distinction is that uncertainty is considered by most authors as a passive element dictated by the environment whilst risk is considered more active and is related to intended actions or current exposures (Brauers, 1986). However, Hertz & Thomas (1983 & 1984) in their highly influential work on risk analysis maintained that risk and uncertainty are essentially the same.

The second distinction alluded to above was highlighted by Arrow(1971), who identified states where situations which are basically certain become uncertain for the individual. This reflects the difference between the objective and subjective characteristics of these phenomena. Using this distinction, risk is seen as something which can be objectively measured (albeit in a ranking of perceived influences), whilst uncertainty is a subjective state of mind. The literature critique presented in the following two sections draws on contributions from number of disciplines, providing a basis for the discussion presented in Section 2.6. (below). This critique supports the following hypotheses.

- (i) Discipline specific assessments of risk and uncertainty have resulted in an ambiguous set of interpretations of both the nature of risk and uncertainty and their effects on the planning process.
- (ii) The spread of a 'risk management culture' draws an increasing number of problems within the sphere of quantitative analysis, independent of the type or level of problem.

2.4 The representation of risk and uncertainty in technology planning and investment analysis.

The material presented in this and the following section (2.5) develop a critique of both current approaches to representing risk and uncertainty, and of applying the output from such representations to develop investment or other policies.

This section takes technology planning and investment analysis as foci of discussion whilst the following section presents a general critique of risk and uncertainty representation and highlights some specific problems.

2.4.1 A review of risk and uncertainty representation in technology planning literature

'Capital Budgeting' is often used as a metaphor in relation to investment analysis and, whilst the two subjects have their own history, there is a large body of material which can be construed as addressing identical problem types. Investment decisions are traditionally based on either Nett Present Value (NPV) or other similar criterion such as Payback Periods, Internal Rate of Return or Return on Investment. Assessments of risk in these types of models usually take the form of sensitivity analysis. This is achieved by either modulating the values of specific variables and assessing the resultant changes in the utility measure, or applying an inflated discount rate to the yearly cash flows to provide a measure of risk exposure. However, these investment analysis techniques provide only partial answers to a series of questions regarding sequential project timing, project life, project exit times and issues of exposure to changes in key variables. In addition, the models used do not explicitly address the possibility that extrapolated cash flows may be incorrectly valued.

Aggarwal & Soenen (1989) took these limitations as a starting point and assessed the costs of terminating a project within the framework of an NPV analysis. Using the output, from their analysis, they were able to draw some conclusions regarding the levels of risk and flexibility associated with any single investment sequence. An associated problem concerns the irreversibility of some investments. Initial work on this problem (Arrow, 1968; Henry, 1974), remained isolated until the contribution of McDonald & Siegel (1986) which concentrated on discrete projects. Much of this work served to call into question the standard NPV criterion that investment should occur when the value of a unit of capital is at least as large as the purchase and installation cost of the unit. The criterion is altered by consideration of the opportunity cost of the initial investment. This means that the value of the unit should exceed the purchase and installation cost by an amount equal to the value of keeping the firm's option to invest these resources elsewhere alive.

Majd & Pindyck (1987) also expanded the critique of simple NPV analyses by analysing the combined effects of construction lag times, opportunity costs and uncertainty (represented in this case by the standard deviation of the applied probability distribution). Their model's output demonstrated the value of construction time flexibility and sequential decision making. The concept of life-cycle costs has added a new dimension to studies of this kind and the above work has been enhanced by studies of life-cycle cost analysis under conditions of uncertainty (Sivazlian, 1980)

A related field of research is concerned with capacity planning or expansion. This may constitute investigations into process or product operations; the timing, sizing or location of these operations; or financial, labour or other resource considerations. Characteristically however, they all address a technologically oriented set of problems. Examples of such studies are to be found in the areas of communications (Yaged, 1973), process industries (Manne, 1967), water resources (O'Laoghaire & Himmelblau, 1974), and waste collection systems (Schultz, 1969). Results from these types of models have been divergent. For example, Haynes et al (1984) found that the

optimal solution to one particular problem varied widely depending on the method adopted.

Grossman & Marks (1977), Tapiero (1979), and Freidenfelds (1980) continued this strain of research, providing the outlines for the seminal work of Davis et al (1987). This paper provided a formulation of the capacity expansion situation under uncertainty as a stochastic control problem, and used Markov type analyses to provide a solution. This indicated that if there are no penalties incurred for accumulating excess capacity, then a policy which involves uninterrupted completion of planned projects is preferable to one which involves partial completion if demand changes. The general form of probability theory presented by Davis et al was that of a piece wise deterministic Markov process (PDP). In their concluding remarks the authors comment that:

"There is, however, a strong negative correlation between model complexity and computational tractability. It has often been observed....that no systematic treatment of integro-differential equations arising in PDP theory is available, and indeed this is not surprising since the behaviour of these equations depends so much on the particular boundary conditions applicable in specific problems."

Generic research into investment scheduling includes work on the selection of interdependent projects (Reiter, 1963; Marglin, 1963), and the incorporation of pricing output decisions and technological change (Hinomoto, 1965). The introduction of dynamic demand and a continuous time framework was undertaken by Erlenkotter & Trippi (1976). Erlenkotter later expanded this analysis to consider the case of planning under conditions of demand and supply uncertainty. In detail, they addressed a water resources problem in a case where a 'surprise' event caused a step change in the demand for the resource (Erlenkotter et al, 1989).

2.4.2 A critique of risk and uncertainty representation in other current literature.

The literature review presented above concerns technology planning and investment appraisal in general. Techniques within these models used for representing uncertainty can be grouped under two headings: Sensitivity Analysis, and Stochastic Tools. This section addresses each of these techniques in turn and develops a critique of their applications.

The use of sensitivity analysis within the types of models reviewed above constitutes an attempt to assess the susceptibility of the dependent variable to changes in other variables used (Alexander, 1989; Patton & Sawicki, 1986). Essentially, the technique involves creating a number of possible future scenarios and determining the effect of these on the overall utility of the project. Selecting which variables to alter and by how much constitutes the major problematic element of this technique. A typical approach is to identify 'key' variables and use values 5-10% either side of the forecast

trend. This constitutes a form of robustness analysis as the dependent variable's stability under a variety of possible scenarios is being tested.

As a learning exercise, this technique can be very useful as it enables influential variables to be identified, thereby helping to develop and focus monitoring and control regimes. As an element of the planning function however, sensitivity analysis is a post hoc tool which is rarely applied to questions of system configuration, system design etc. Furthermore, its successful use is dependent upon initial forecasts being broadly accurate as the sensitivity of the dependent variable will be exposed relative to some base point (the original forecast). Alternatively, the range of the sensitivity analysis may be operating at the edge of a step function thereby providing little information about the interactions between the various cost elements.

The widespread use of sensitivity analysis is a function of the domination of a financially focused approach to technology planning. The uncertainty which is under examination typically concerns the costs of technological components, fuels, skills etc. The system and component design parameters are taken as set and there is little if any analysis of the effect of alternative system configurations.

The use of probability distributions to represent uncertainty has enjoyed widespread popularity over the past 10-15 years. However, there appears to be little evidence for the development of a standard approach to using probability theory for this specific purpose. Irrespective of the particular use to which a probability distribution is put, there are three fundamental reasons why it is inappropriate in the context of technology planning and investment appraisal.

Firstly, the basis of probability theory rests on the repeatability of the experiment which is used to construct the distribution. This is clearly an impossible operation given the unidirectional nature of time and the complexity of the system being studied. Hence, the derivation of a distribution is both theoretically problematic and highly subjective. Assuming that such a distribution can be validly constructed, its relevance to the planning and operation of a complex technological system is questionable because there will be no 'set' of events, only a single event sequence. What is being illustrated here is the fact that using a probability distribution as a guide to decision making makes little sense because only one event sequence will unfold. There will be no repeated runs of reality and so we will never have the opportunity to experience the remaining possibilities. Hence, the investigation may be more beneficial if it were focused on the disutility associated with not encountering the event. (These comments are relevant to both cases where a probability distribution is applied to a single value and where it is applied across values.)

Secondly, the mathematics used to analyse continuous probability distributions or probability density functions can only be used for simple, well defined cases. The set of distributions which can be used is therefore limited and does not include discontinuous, broken or step functions. The commonly utilised examples are normal, log normal, beta and gamma. Selecting between these and choosing a range of values for analysis is a subjective process which is often influenced by the practicalities of the calculation routines rather than by any reference to possible future states.

Finally, the cumulative aspects of applying probabilities to either events or states (conditional probability theory), creates a situation where the existence of a discrete state at a time $t > 0$ becomes highly improbable. In order to reduce the complexity of the analysis and avoid the sequential problems resulting from applying probabilities to incremental states, most models adopt a method by which the probability distribution is specific to certain events or summated values.

These comments which argue that an inappropriate application of probability theory has been widespread, may appear to be out of place given the extensive employment of this technique to many types of problem. However, if attention is given to the development of probability theory, adequate evidence with which to support the reservations can be found. For example, it has been disputed as to how probability theory can account for single events when it is often conceptualised as the mathematical limit to which the frequency of an event tends in the long run.

Examples of many of the shortcomings of popular approaches to the use of probability theory to represent uncertainty can be found in papers on capacity expansion planning (e.g. Erlenkotter et al 1989). Support for, and alternative approaches to, probability theory can be found in Kyburg (1970) and Swinburn (1973). The most fundamental criticism used above (that of no unlimited event repetition) is dealt with in von Mises (1928 pp13-14) where a series of additional limitations are expounded.

Alternative methods for representing uncertainty have been developed and include fuzzy sets, interval analysis, and possibility distributions (see Behrens & Choobineh, 1989 and Choobineh & Behrens, 1992 for an exposition). The proposition of this thesis however is that these alternatives remain rooted in a mechanistic view of the nature of uncertainty. This is expressed by seeking to capture the behavioural and conceptual elements of uncertainty with a view to reducing the effects of doubt and increasing confidence in subsequent decision making. As outlined below, the approach promoted in this work is to consider uncertainty as an intrinsic element of the future and to accept the view that forecasting has a limited role in formulating strategy.

2.5 A general critique of current approaches toward representing and addressing risk and uncertainty.

Three elements of current approaches to handling risk and uncertainty (as reviewed in the previous two subsections) are open to criticism and each of them is dealt with in turn in the following paragraphs.

2.5.1 The trend towards quantification.

Knight's original distinction has been passed down through the literature and accepted as a useful academic if not a practitioner demarcation. As such, the only criterion by

which risk can be identified as being distinct from uncertainty is the existence or application of a probability distribution within which to analyse the possibility of any one state occurring. Elements of uncertainty have therefore been turned into elements of risk as and when some measure of either objective or subjective probability could be applied. The resultant analysis has then become accepted as risk based, independent of the type or form of the probabilities being analysed.

It should be noted here that the basis of Knight's distinction is itself subjective in form. The assignment of distinct probabilities is a process open to debate and therefore prone to differences in individual perspectives, knowledge, and willingness to commit impressions to record. Furthermore, the requirement that a probability be well defined has led to elements of uncertainty evolving into elements of risk as techniques for analysing and quantifying an ever mushrooming range of phenomena have been developed. This fact was noted by Levy & Sarnat (1986) in a footnote to their introductory comments on risk and uncertainty and yet appears to have prompted little progressive thought.

Knight's semantic distinction between risk and uncertainty results in a potentially misleading conceptual disparity as risk becomes objectively measurable or quantifiable doubt, and uncertainty something which is perceptual in nature and human centred. Why then has there been this ready shift of elements from uncertainty into the sphere of risk? The answer to this question may be related to the *raison d'être* for doing risk and uncertainty analyses; the planning function itself.

Planning processes rely heavily upon the quantification of information. Decision makers prefer to be informed about options in a form which lends itself to ordinal processes of selection and allows some measure of both internal and external audit. As an inherently uncertain but dominant element of planning, 'the future' requires quantification. Saying "I don't know" or "I'm not sure" reeks of indecisiveness and ignorance. Consequently, there is a desire to quantify and rank the levels of risk and uncertainty associated with the future.

2.5.2 The dominance of a rational / scientific viewpoint and the problem of developing a policy level approach to assessments of risk and uncertainty.

The second criticism of current approaches to handling risk and uncertainty centres on the methodologies which drive most of the techniques adopted in both academic and commercial environments. Historically, the mechanistic view of our world has been an omnipresent influence on the problem solving methodologies and techniques which most Western / Judeo-Christian societies utilise. The success of this approach in certain areas has been nothing short of astounding. However, it has been seen as a pertinent framework with which to approach all epistemological centred activities. This trend has strictly bounded our investigative methodologies and consequently restricted our options for action. Investigations into risk and uncertainty have not escaped the influence of this paradigm.

The mechanistic view suggests that disaggregated, atomistic, and quantitative analyses are required in order to gain an understanding of the world and its contents. Such an understanding enables explanation and prediction. The developers of specific techniques have never claimed to have isolated a mechanism for eradicating uncertainty. However, the underlying methodologies remain rooted in an approach which promotes solution driven investigations. Risk and uncertainty have subsequently been viewed as problems to be solved or criteria to be optimised (minimised).

One consequence of the influence of a mechanistic view in research activities is that there is scope for a wide variety of modelling activities. Hence, whilst the world is viewed in mechanistic terms, the complexity of the mechanisms are such as to dictate a research approach which disaggregates processes and structures them in a way which facilitates the modelling activity. One example of the way in which this approach has retarded advances in the development of prescriptive theories can be found in the literature on the relationship between environmental uncertainty and the organisation.

Starting with Dill (1958) and continuing with Lawrence & Lorsch (1967), Thompson (1967), and Duncan (1972), the relationship between organisations and their operating environments has come under increasing investigation. The study of environmental uncertainty forms a large subset of this research field (Burns & Stalker, 1961; Galbraith, 1977). The assumption behind this strand of research is that the activities of key decision makers within an organisational environment are strongly influenced by incongruencies between the actual operating environment and individual perceptions of it. There was therefore a prolonged attempt (peaking in the mid 1970s) to isolate the sources and magnitude of these incongruencies. In summary this research programme did nothing more than expose both contextual and subjective variances which can cause divergence in the perceptions of uncertainty and has produced little useful input to the development of practitioner techniques.

2.5.3 The influence of perception and perspective on uncertainty assessment.

The final element of the critique presented here concerns the issue of multiple agendas. Some elements of risk and uncertainty which are subjective in nature may appear to be open to techniques of aggregation, typological distinction etc. However, any subjectively based opinion or quantification will exhibit variations across time, cultures, social position, organisational position, gender, and value system. Furthermore, one individual may adopt different subjective positions on a single issue dependent upon his/her frame of mind or which 'hat' he or she is currently wearing (e.g. work hat, parent hat, investor hat etc.). It is therefore difficult to appreciate the value of studies and techniques which attempt to isolate elements of uncertainty and assess subjective measures of them for use in some aggregated model of organisational behaviour or risk/uncertainty resolution.

In summary, the majority of the research carried out relating to issues of risk and uncertainty have possessed two distinct characteristics.

1. They have been dominated by the prevailing rational / scientific approach to problem solving.
2. As a result of (1), they have been discipline specific, exhibiting a paucity of synthesis and integration at the policy or strategy level and having little influence on the development of policy instruments.

Generally, investigations have concentrated upon either the development of an understanding of perceptions of risk and uncertainty (a qualitative approach adopted mainly by practitioners of the social, organisational, and management sciences), or the formulation of calculative routines with which to assess the risk and / or uncertainty (an essentially quantitative approach adopted by O.R. / M.S. practitioners, decision analysts and economic / financial modellers.) The literature review presented above highlighted the fact that research into the phenomena of risk and uncertainty has developed into a number of discipline specific areas (Krimsky; 1992, attests to this trend with reference to a particular problem). Furthermore, it is contended that this mode of research neither clarifies the relevant issues nor identifies possible strategies which organisations can adopt in order to address uncertainty. (A notable exception to this trend being the field of flexible manufacturing systems which, thanks to the level of physical control possible over its constituent elements, has been successfully developed using O.R. techniques.) Attempts at synthesis of theory and interdisciplinary analysis have been both few and far between, and too readily ignored.

The need for synthesis in strategy / policy analysis has been emphasised in Chapter 1. With specific reference to risk and uncertainty, this need is strengthened due to both the nature of risk and uncertainty (i.e. their omnipresence and relevance to all aspects of the planning function), and the need for policy development to address diverse aspects of the core problem. The following section develops the critique presented above and suggests a revised interpretation of risk and uncertainty which is of greater relevance to policy support studies.

2.6 Towards a policy oriented taxonomy of risk and uncertainty.

The discussion presented in Section 2.3 concerning the nature of risk and uncertainty provides a basis for a reassessment of these phenomena. By applying the concept of uncertainty to all future events, it is implicitly declared that plans for the future will be exposed to a host of influences which are as yet unknowable and uncontrollable. There will therefore be the possibility of an unintended or undesirable outcome to our actions. The difference between these two types of result is crucial to a revised approach to risk and uncertainty. Without the possibility of an undesirable outcome, rather than an unintended one, there is no risk associated with our current actions. Risk thereby becomes a function of two elements; a) The likelihood of the undesirable event occurring and b) the level of disutility associated with the undesirable outcome.

2.6.1 A reinterpretation of the nature of risk and uncertainty.

This characterisation of risk and uncertainty clarifies Knight's approach by proposing that:

- a) Uncertainty is an omnipresent and inherent feature of our world, reflecting man's inability to predict future states of his environment..
- b) Given the need to engage in some form of planning for the future, risk is characterised as a function of:
 - i) The mismatch between intended or desired future states and actual realised future states.
 - ii) The level of disutility associated with such mismatches (Sampson & Smith, 1982).

Within this framework, uncertainty reduction is a matter of debate and conjecture whose positive contribution is the eradication of subjectivity. Risk analysis becomes applicable to both those cases where there are well defined and accepted probability distributions, and those where subjective assessments of possible outcomes are utilised. Risk reduction then focuses on limiting the gap between expectations and results, and minimising the potential for disutility.

A curious though highly relevant consequence of this interpretation of risk and uncertainty is that an acceptance of uncertainty as an inherent and omnipresent element of the future actually reduces the associated risk. This occurs because expectations about intended or desired future system states are modified in response to the uncertainty. Hence, the level of mismatch between desired and actual future states is lowered. Embracing uncertainty rather than viewing it as a threat thereby reduces risk by changing expectations and generating broader utility measures. An example of this will be demonstrated in the survey of Israeli managers and modellers reported in Chapter 5.

Formalising the phenomena of risk and uncertainty in these terms highlights the interdependence of them as conceptual constructs. Without uncertainty about the future, there would be no risk; and the possibility of risk does not arise in the absence of uncertainty. This synergism of constructs between the two phenomena makes it difficult to dissociate the two on a practical level. However, such dissociation is essential if practitioner based methods and techniques for addressing risk and uncertainty are to be clearly formulated and unambiguously transmitted to policy makers and strategists.

From the above description, reducing uncertainty is both unfeasible due to the phenomenon's subjective nature and would in any case be ethically undesirable as it would repress opinion and free thought.. However, one particular aspect of uncertainty has been overlooked in the above analysis. The concept of uncertainty is

From the above description, reducing uncertainty is both unfeasible due to the phenomenon's subjective nature and would in any case be ethically undesirable as it would repress opinion and free thought.. However, one particular aspect of uncertainty has been overlooked in the above analysis. The concept of uncertainty is rooted in the idea of multiple possible futures and our lack of knowledge concerning those futures. For the remainder of this thesis 'uncertainty' will be taken to indicate a lack of knowledge about the future rather than a belief about the future. This allows an emphasis on objective as opposed to subjective analyses and promotes policies which provide the potential for change in order to adapt to diverse environments.

2.6.2 Management sovereignty and the bounds to formal analysis; a taxonomy of knowledge and influence.

Prescriptive applications which may emanate from this interpretation of risk and uncertainty will be constrained by a revised appreciation of what is feasible in the realm of planning and control. In essence this constitutes a new 'realism' in planning and associated fields such as decision analysis and investment appraisal. Generally, this realism promotes a debate concerning the matching of tools and methods to the types of control which are possible over various aspects of the organisation's environment. Specifically, this means distinguishing between situations where some measure of *control* can be exercised, situations where *influence* is the most relevant level of manipulation. and those situations where *impotence* must be accepted (a similar distinction is expounded in Ackoff, 1970). These distinctions constitute a bounding of management sovereignty and are of sufficient interest to warrant elaboration.

Elements of *control* will consist of those processes where both input and output parameters are within the predictive capacity of management. Empirical research from the field of organisational behaviour has suggested that decision makers overestimate the extent to which outcomes of a strategy are under their control (Langer, 1975; Langer & Roth, 1975; Larwood & Whittaker, 1977). Such evidence points to overconfidence in the tools of planning and control and highlights the need for a reassessment of the scope of management authority. *Influence* will relate to situations where only marginal or partial levels of authority are achievable over the parameters of interest, and *impotence* designates processes where management are powerless to affect the future state of some variable or structure. Although most strategy level situations involve complex combinations of all three elements, there is benefit to be gained from identifying the domain of each element for any particular situation. This, in turn, would enable the scope of analysis and response tools to be more closely matched to management's potential rather than to management's needs.

A complementary taxonomy can be proposed relating to the quality of information which the organisation is capable of accessing regarding elements of its own or its operating environment's performance or behaviour. Complete confidence in the knowledge of relationships or behaviour can be characterised as *certitude*. Knowledge of the phenomenon but incomplete understanding regarding its behaviour constitutes an *awareness* of the phenomenon. Finally, *ignorance* characterises a

of confidence by an organisational actor but rather to the success of formal analysis techniques as predictors of system behaviour. It is therefore objective rather than subjective in nature.

These propositions concerning the extent and nature of management control and knowledge provide opportunities for the development of new strategies for dealing with turbulent environments. Such strategies are already to be found in specific commercial settings and constitute a shift in emphasis with regard to the planning process. In particular the focus of effort will be drawn away from a predict and prepare mentality towards the adoption strategies which focus on the promotion of resilience. The purpose of these will be to allow the organisation to achieve a series of beneficial attributes, such as possessing the ability to change product lines or process operations quickly or to alter the financial structure of the company at short notice. Such 'potential for change' if present in a fundamental form (i.e. possessed by the base elements of any organisation....people), allows the organisation to not only change in response to short term fluctuations in its environment but also to respond to more fundamental changes in, for instance, value systems or social attitudes.

The two taxonomies discussed in the above paragraphs will be revisited in Chapter 10 where they will be utilised as part of the framework for discussing the thesis' contribution (§ 10.4)

As noted above, the dominance of a 'predict and prepare' approach to planning is challenged by the revised characterisation of risk and uncertainty presented in Section 2.6.1. The suggested alternative approach is focused on ideas of resilience. The following section introduces some recent developments in several academic fields, all of which adopt analogies from evolutionary or ecological theories to provide a framework for problem analysis. The relevance of these analogies is emphasised and a revised approach to coping with risk and uncertainty is proposed.

2.7 The use of evolutionary analogies as a basis for developing strategies with which to address risk and uncertainty.

As noted above, the prescriptive approaches to addressing risk and uncertainty which have emerged from the general inquiry fields of planning, organisational theory, operations research and others, have tended to be framed within essentially reductionist and mechanistic paradigms and methodologies (Parson, 1985).

This type of reductionist / deterministic approach is related to the classic distinction between risk and uncertainty as being the difference between quantifiable factors and purely perceptual factors. The development of new techniques for quantifying certain aspects of an organisation's activities has transferred the future state of such elements from being one of uncertainty to being one of risk, independent of the validity or relevance of the quantifying process. This is not to say that such analyses are of no use. The frameworks within which many of the available techniques are currently used allows resultant benefits to be both closely defined and validated by either experimentation or experience via time series analysis. However, the emphasis upon

measurement and quantification has led to an approach to the problems of risk and uncertainty which promotes several inherently undesirable features from a planning perspective. These include; the promotion of a "predict and prepare" mentality, focusing elements of the planning function on forecasting, and reliance upon the optimisation of specific objective factors within the organisation's activity or achievement set.

Recent work in the fields of complex systems, ecological systems and macro-economics (Allen, 1990 and Nelson & Winter 1982), have attempted to develop an alternative approach to the analysis of natural and other types of system based upon evolutionary analogies. These approaches formulate the problem of risk and uncertainty in different terms, accepting uncertainty as an inevitability (Allen, 1992), and seeking to develop models which reflect the interaction between populations or 'sets' of elements within a continually changing environment. Evolutionary change is seen as resulting from what has been removed in the reduction to the deterministic description - i.e. non average elements. Optimisation as a solution technique and end state planning as a dominant methodology are replaced by alternative factors such as resilience, flexibility, robustness, consensus, adaptivity, and process planning. Formulative theorists in this field represent a number of disciplines and include Tintner (1941), Weaver (1948), Alchian (1950), Simon (1962), Winter (1964), Jantsch (1967), Prigogine (1984 & 1985), and Mannermaa (1986).

Differentiating between the two approaches discussed above (Mechanistic and Evolutionary) as they relate to an analysis of risk and uncertainty within a framework of complex systems provides the classification presented in Figure 2.2

Figure 2.2 Comparison of problem solving approaches as determinants of emphasis in risk and uncertainty analysis.

PARAMETER ↓	MECHANISTIC APPROACH	EVOLUTIONARY APPROACH
VIENS UNCERTAINTY	FAILING OR FAULT TO BE RESOLVED OR ELIMINATED	UNAVOIDABLE. INHERENT ELEMENT OF FUTURE
PRESCRIPTIVE PHILOSOPHY	PREDICT AND PREPARE	ADAPTIVE STRATEGIES. PROMOTION OF DIVERSITY, LEARNING, EXPERIMENT AND CHANGE
FOCUS OF CONTROL	STATES	ATTRIBUTES
ANALYSIS TOOLS USED	REDUCTIONIST. CAUSE-EFFECT AND PREDICTIVE MODELS. OPTIMISATION TECHNIQUES	SIMULATION MODELS. EMPHASISES RELATIONSHIP BETWEEN AVERAGE AND NON AVERAGE FACTORS
CHARACTERISTIC MANAGEMENT STYLE	FORMAL. FORMALISED INFORMATION GATHERING	INFORMAL. EMPHASIS ON HUMAN CENTRED ATTRIBUTES

This diagram will be employed again in Chapter 10 where it is used to provide one element of an interpretive framework for the research findings.

Evolutionary analogies have previously been suggested as potentially useful in the field of planning. Up until the early 1980's there were two identifiable methodologies for dealing with risk and uncertainty within the planning process (indeed the planning process itself has, in recent years, been focused almost exclusively on issues of uncertainty). These methodologies can be summarised as follows;

- 1) **Predict and prepare:** Reliant upon forecasting the future and preparing the organisation for the expected developments.
- 2) **Control and Influence:** Dependent upon the organisation being able to shape its environment and dictate or at least influence key variables.

Over the past decade an alternative to these two approaches has been developed which focuses on adaptive and flexible response as desirable organisational attributes. The ramifications of this new approach has been particularly evident in the strategic management field. The role of variety in strategic planning has been identified as accompanying a shift away from a problem solving approach ('What should the firm plan to do?'), towards a control focused approach ('What should the firm plan to be able to do?'). (Burton, 1984). However, much of the strategic management literature fails to address the question of how adaptivity, flexibility etc. can be achieved on anything other than an organisational structure level. This fact accounts for the emphasis on 'change management' in the management literature at the expense of analysis techniques for assessing resilient technological and economic configurations. Additionally, issues of diversity generation and the identification of flexible strategy positions have been poorly covered.

The types of evolutionary analogy referred to have also enjoyed some popularity in the field of organisational theory (Astley & Van de Ven, 1983; Zammuto, 1988). Hannon & Freeman (1977), tracing the roots of their approach to Hawley (1968), argue for a reformulation of the problem of environmental effects on organisations in population ecology terms. Their findings suggest that the concrete implication of generalism for organisations is the accumulation and retention of excess capacity. In commenting on the need to identify environments where generalists are favoured over specialists, Hannon & Freeman propose the use of Levins' theory relating the nature of environmental uncertainty with optimal levels of structural specialism (Levins, 1962). Evidence for such generalist / specialist mixes have more recently been identified by Carroll (1984).

Other closely related research can be found in a number of disciplines. However, the main contributors act on the fringes of their own fields. Such work is often being difficult to categorise and therefore publication is relatively problematic. Examples of relevant sources include Jones & Ostroy (1984) - Economics; Allaire & Firsirotu (1989) - Organisational Science; Sperling (1982,1984) - Decision Analysis; Sachdeva (1984) - Development Planning.

It should be noted that it is as yet unclear to what extent the biological analogies which form the basis for evolutionary focused analyses can be taken. However, as an

alternative framework within which to analyse aspects of system behaviour, particularly within the context of environment / population interaction, the evolutionary model provides a useful descriptive template. With respect to this study, several elements of the evolutionary model can be mapped onto assessments of risk and uncertainty so as to establish an alternative set of foci for analysis.

2.8 Interpreting the characteristics of systems which promote sustainability.

Emergent from both the discussion of the nature of sustainability presented in Section 1.2, and the adoption of an evolutionary approach to handling risk and uncertainty is a need to address issues pertaining to the framing of the problem. To be more precise, the concepts used in defining the desirable attributes of the technological system, themselves require some framework within which the various terms and images can be developed. It is the purpose of this section to provide such a framework.

Given the problem of investigating those technological system properties which promote sustainability there are a number of approaches which could be adopted. However, the relative nature of the characteristics being analysed provides a ready framework for assessing the key attributes. As discussed in Chapter 1, sustainability is not only an elusive concept to apply to a physical system, but its assessment is also relative to the surrounding environment. Similarly, the attributes which promote sustainability (flexibility, diversity, resilience etc.) are relative concepts. The following paragraphs seek to develop a conceptual map of these attributes in order to focus the research effort.

2.8.1 Resilience.

The concept of resilience suggests an ability to overcome setbacks or potentially damaging changes in the environment. It is defined as '*an ability to recover from or adjust easily to misfortune or change*' (Websters New Collegiate Dictionary, 1974), or '*have or show recuperative power*' (Concise Oxford Dictionary, 4th Edition, 1951). It thereby suggests continuation and a resilient system will be a surviving system. Holling, writing in relation to environmental systems, remains true to this interpretation by stating that '*resilience is a property that allows a system to absorb and utilise (or even benefit from) change*'. However, Holling does recognise that there may be analogies in other types of system:

'Our concept of resilience emerges from a very specific understanding of the structure and behaviour of ecological systems. It seems to have a counterpart in the behaviour of institutional and other systems.' (Holling, 1978)

Adapting the analogy to technological systems provides an example of the hierarchical system description which was alluded to in Section 1.2. A resilient technological system needs to be resilient with regard to some external variable(s). The desire to achieve long term system performance stability was proposed as a

simple objective function. From this it is possible to construct a listing of environmental changes which it is desirable for the system to be resilient against. For example, short and long term variations in fuel prices, changes in technology design, changes in pollution standards, changes in demand and population patterns. Any system configuration which maintains its desired performance characteristics under these circumstances would then fulfil the criteria of resilience.

Drawing on these contributions, the phenomena of resilience will be interpreted with regard to technological systems as; 'the capacity of the system to achieve a desired set of performance criteria under both quantitative and qualitative changes in its operating environment.' This may appear to be too broad a distinction to be of any use in investigating resilience as a characteristic. However, the nature of the phenomena itself dictates such a denotation and it is one of the purposes of this study to identify specific attributes and enhance the definition provided.

2.8.2 Robustness.

An associated term which is often used as a synonym for resilience is that of robustness. Formal definitions of robustness refer to the exhibition of strength or health (another pair of survival characteristics). In particular, the concept of robustness has been utilised extensively in developing decision support tools and has found a wide application in the fields of Management Strategy and Operational Research. Robustness is defined by Rosenhead et al (1972) as '*a measure of the useful flexibility maintained by a decision.*' Hence, a decision which results in action that maintains more options for future decisions is more robust than one which offers lesser degrees of choice. Expanding the work of Rosenhead et al within an entropy focused framework, Pye (1978), phrases robustness in terms of '*trading off flexibility against expected value*', and demonstrates how the cost of flexibility may be estimated and controlled. One interesting cross-disciplinary point about Pye's paper is its inclusion of an analogy between Friend & Jessop's approach to handling uncertainty and Ackoff's work on decision making.

Friend & Jessop, writing on local government planning issues relate robustness to the '*leaving open of options*'. They view robustness criteria as helping to strike a balance between current commitment and flexibility of future choice:

'...in making a choice of immediate actions as opposed to stating a preference between ultimate solutions, it may be important to take into account in some way, an assessment of the value of retained flexibility for the future.' (Friend & Jessop, 1969)

These references are focused on the robustness of decisions and decision sequences. However, maintaining options for future action, whilst instilling flexibility in the decision sequence, only results in a particular type of robustness. By effectively creating a diversity of decision paths, the robustness of a strategy or project management *process* can be achieved. Accomplishing robustness for the strategy itself is dependent upon a wider range of attributes.

Robustness can therefore be viewed either as the property of a system analogous to resilience (the two terms having their common application in different fields), or as a direct measure of a single action reflecting its impact on the diversity of future options. For the purposes of this thesis, the term of preference to describe the ability of a system to survive changes in its operating environment will be 'resilience' (see above). Furthermore, the phrase 'resilient strategy' will be avoided as it suggests that the strategy itself is resilient whereas what is being sought is the resilience of the system in order to ensure sustainable resource provision. Hence 'strategies focused on resilience' or similar terminology will be used to denote a planning approach which seeks to promote resilience of the system. Use of the terms 'robust' and 'robustness' will be limited to indicate increased confidence in the validity of a data set or technique.

2.8.3 Flexibility.

The discussion of resilience and robustness presented above includes some reference to flexibility. This property constitutes a core element of sustainability and relates to a capacity to react or respond to changing circumstances. Dictionary definitions of flexibility often include references to adaptability (e.g. The Concise Oxford Dictionary). However, the two terms have been ascribed specific meanings in different research fields, and the following discussion attempts, where possible, to derive a general interpretation of these expressions.

As with robustness, the field of management science has provided an interpretation of flexibility within a decision theoretic framework. Pye (1978) views flexibility as '*the number of future alternatives from which a choice may be made.*' Writing on industrial planning, Hall (1983), notes that '*flexibility means that plants should be capable of switching very quickly from one product to another or from one part to another....almost instantly.*'

Much work on the concepts and application of flexibility has been accomplished in the field of manufacturing systems (Zahran et al, 1990); The qualitative nature of such flexibility has been addressed by Buzacott (1982) whilst the quantitative elements are best reviewed by Chatterjee et al (1984). As with diversity (see below), the concept of entropy has been utilised to provide a reference for measurement (Kumar, 1988). Taking production systems as a generic focus, Brill & Mandelbaum (1990) address the issues of flexibility and adaptivity in a way which is of particular relevance to this study. In particular they view measures of flexibility and adaptivity as forming '*a basis for comparing existing or potential systems, quantifying how flexibility or adaptivity trades off with cost, selecting and designing new systems etc.*' They go on to characterise adaptivity as measuring how a function of flexibility changes from situation to situation, as the system evolves. Furthermore, Brill & Mandelbaum draw attention to the relationship between flexibility and adaptivity:

'Measures of machine adaptivity are defined in terms of flexibility, which are relative to task sets, their weights of importance and the machine task effectiveness measure, all of which are subject to change over time.'

Mandelbaum & Buzacott (1990), in what represents an interesting cross-disciplinary study apply formal decision theory to the ideas of flexibility posited by Gupta & Rosenhead (1968) and Rosenhead et al (1972). They propose that flexibility is required in a system or process so that *'it is able to respond to change in the system's environment or to a change in the decision maker's perception of reality.'*

In other fields, flexibility has been explicitly viewed as a tool for addressing issues of uncertainty. Carlsson (1989), taking his motivation from Stigler (1939), Marschak & Nelson (1962) and Vives (1986 a&b), attempts to integrate notions of flexibility with those of risk and uncertainty into a descriptive classification of flexibility as it is found within engineering firms. In addition, the subject of flexibility as a strategic planning element for investment sequences was taken up as a study area by both Sawhill & Silverman (1983) and, as noted in Section 2.4.1, by Aggarwal & Soenen (1989).

The preceding examples expose the clear relationship between the concepts of flexibility and change. Flexibility can be seen as the potential for change (Gupta & Goyal, 1989). Adopting a flexible stance requires one to have options for action; a flexible plan is one which provides for change to occur during the plan execution. Hence, in the following text, 'flexibility' is used to indicate a potential for change or the existence of alternative positions / strategies / configurations that the system can adopt.

2.8.4 Adaptability.

In order to effectively exploit flexibility, the property of adaptability (or adaptivity) is required. If flexibility is the potential for change, then adaptability is the ability to execute or exploit such change. Hence, a system may be flexible (have options for alternative action), but not adaptive (be able to utilise these options). This is a marginal distinction and the two terms are commonly used interchangeably. Most discussions of adaptiveness are couched in the terminology of the biological and ecological sciences. However, the field of General Systems Theory has been prominent in interpreting the key concepts from ecology and biology which are utilised (by analogy) in planning and modelling activities. Shakun (1981) characterises an adaptive system as one that *'reacts or responds to change to attain goals'*. Such change may be internal or external and the response type may be passive (changing itself) or active (changing the environment). Shakun views both reactive and responsive systems as being essentially adaptive.

In the management strategy field adaptation has been defined as the *'process by which an organisation and its environment reach and maintain an equilibrium, ensuring the survival of the system as a whole.'* (Lawrence & Dyer, 1983). Whilst the use of the term 'equilibrium' is open to debate in this context, the definition does emphasise the

process character of adaptation and furthermore introduces the concept of survival as an objective function.

A concept which is grammatically allied to adaptivity but which refers to a measure of success in surviving is that of 'adaptedness'. In terms of ecological or natural systems the term adaptedness possesses a particular meaning allied to 'fitness'. It has been viewed as the '*ability of an organism to survive and reproduce in an environment*' (Dobzhansky, 1969), or '*conformity between the organism and its environment*' (Pianka, 1978). In biological terms, fitness is associated with birth rates and the ability to recreate and is thereby a relational property, '*reflecting the interaction of an organism and its environment*' (Rosenberg, 1983).

From these comments it is clear that adaptiveness is a dynamic process of interaction between a system and its environment. This results in a variations of the former's behaviour in response to changes in the latter's condition in pursuit of a desired condition or set of goals.

2.8.5 Diversity.

A further contributor to sustainability is diversity. A useful interpretation of diversity with regard to ecological systems is provided by Pielou (1975) who comments that '*diversity bears to qualitative observations the relationship that variance bears to quantitative measures.*' Pielou also emphasised the need to define the members of a community which was being analysed for diversity and also the desirability of matching any index of diversity to the particular properties and characteristics of each community. A simple, statistically based measure of diversity derived from entropy theory was provided by Simpson (1949), and has been used extensively as an index of concentration or dominance. The index measures the probability that any two individuals picked independently and at random from a community will belong to the same family. It thus provides an inverse measure of diversity and has been widely used in ecological studies. Other entropy based measures have used an information theory based approach to the problem (Hackbart & Anderson, 1975).

In its elementary sense, diversity alludes to the number and relative proportions of different typological groups in a community. However, there are numerous types of diversity which could be analysed (diversity of form, size, behaviour, age etc.), leading to a potentially complex description of any single community. (Indeed the diversity of diverse characteristics could itself be analysed.) Diversity can also be represented in a variety of ways, for instance through innovation or, as will be demonstrated in Chapters 3 and 4, through redundancy. The difficulties surrounding the derivation of a robust definition for diversity has been highlighted by Maliza & Ke (1993). Hence, diversity as a concept is relatively straightforward; its measurement and analysis however is both relative to the objective of measurement, and potentially complex.

Diversity has an obvious relationship to variety and the two terms, having closely related dictionary definitions, are often used interchangeably (diversity: '*unlikeness*;

different kind; variety' Concise Oxford Dictionary. 4th Edition, 1951). However, there has been a suggestion that variety should refer to variability within a set of attributes whereas diversity should relate to variances in the types of sets of attributes. This classification is unhelpful as the terminology would be dependent on what level of attributes are being discussed (i.e. the components of a particular system could exhibit both variety and diversity dependent upon which focus of interest is adopted or how the 'system' is bounded).

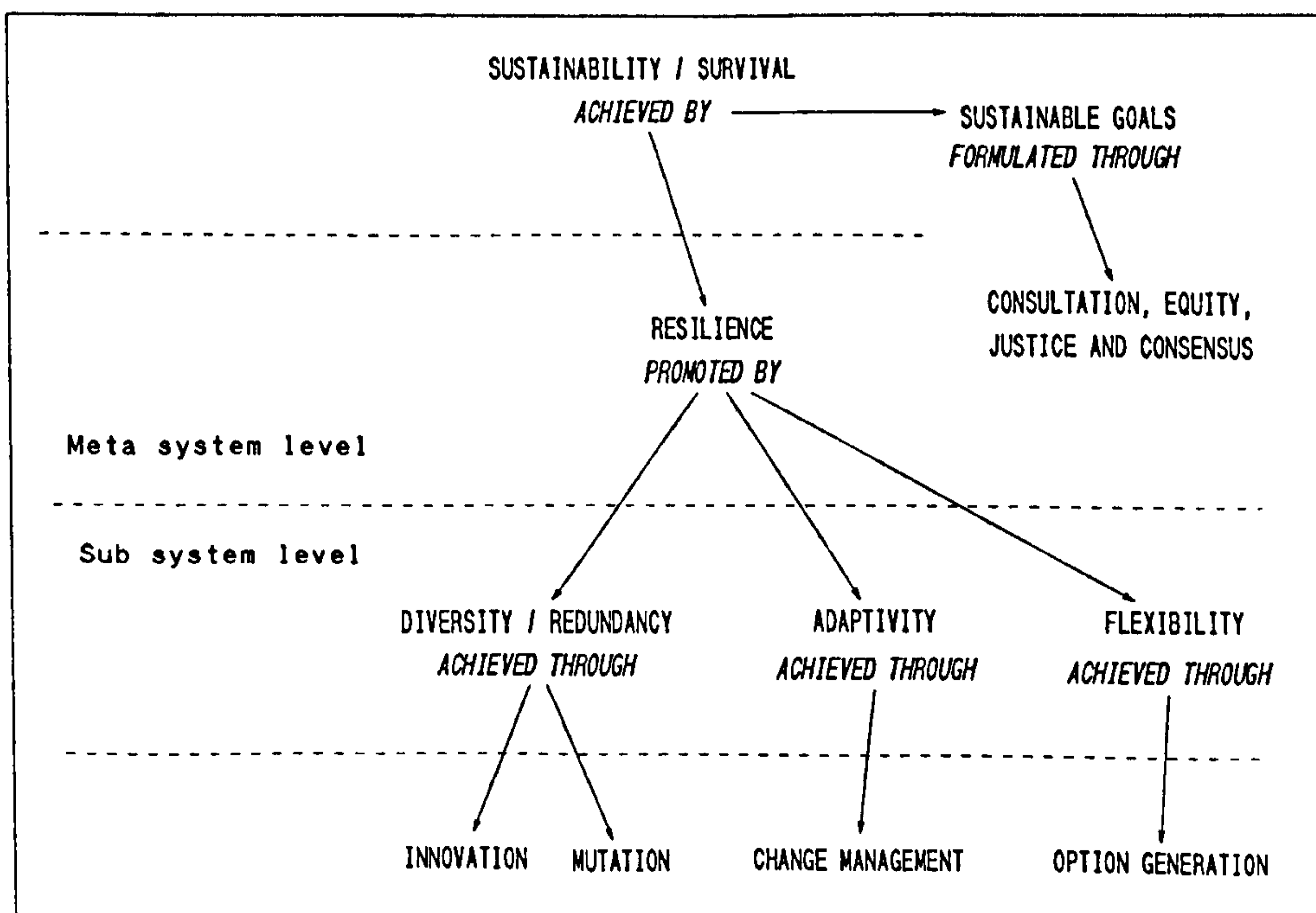
Identifying the multiple levels at which diversity can have an influence emphasises again the hierarchical nature of the concepts being described in this section. However, the number of levels at which variances may be identified makes the consistent use of 'diversity' and 'variety' problematic. Therefore the term diversity is used throughout this study to denote variations in attributes or attribute sets.

These then are some possible constituent properties of a system which promotes sustainability of resource supply; resilience, robustness, flexibility, diversity and adaptiveness. The relationships between the factors are as important as their individual attributes and the following section addresses these connections.

2.9 Interpreting sustainability within the context of technological systems.

Each of the attributes discussed in the previous section contributes towards sustainability. One of the main issues addressed in the following chapters however is whether and how analogous technological attributes may be isolated and assessed so as to ensure the sustainable supply of specific resources. In order to provide a framework within which to discuss the relative qualities and roles of the attributes discussed in the previous section, Figure 2.3 illustrates the conceptual relationships between each element.

Figure 2.3 Conceptual relationships between elements of sustainability.



2.9.1 Interactions and influences between the constituent elements of resilience.

As was posited in Section 1.2, sustainability is achieved by having both sustainable goals and engendering resilience in the target system. (It is relevant at this point to re-introduce the concept of survival which is analogous to sustainability under conditions where the latter is not temporally constrained.) Resilience, in turn, is promoted (although not necessarily secured), by both:

- a) Maintaining structural and / or functional diversity thereby providing options for change.
- b) Promoting both the potential for change (flexibility), and the ability to change (adaptivity) in the system's plans, configurations and functions. (*'reorganising a system's resources'* Shakun, 1981).

There is a level of synergy between these two elements of resilience in that flexibility or adaptivity is often accomplished through the utilisation of diversity. A concept related to diversity is that of redundancy. Redundancy raises the issue of over-investment and one of the most influential management strategy theorists of the post-war period has said that flexibility runs contrary to the fundamental principle of the industrial age - i.e. maximising profit via specialisation (Ansoff, 1975). However, redundancy does provide some measure of flexibility, and its nature has been investigated by, amongst others, Petrovic (1991), who analysed the role of both parallel and standby redundancy to improve systems reliability.

Diversity (or redundancy) can be achieved via both innovation and mutation. Innovation relates to the generation of novel or new system attributes. Mutation refers to the modification of an existing element. The boundary between these two functions is imprecise as innovation is often the result of a mutation of ideas if not of physical components. The constituents of flexibility and adaptivity are more difficult to identify although there is a strong element of *'options generation'* associated with the former and of *'change management'* associated with the latter. Indeed, one of the few cross disciplinary works on adaptivity (Holland, 1975) views its salient features as *'modification of structure or behaviour'*.

A further interesting feature of Figure 2.3 is its illustration of the multiple dependence of any one attribute upon both sub and meta-system characteristics. Hence the resilience of a technological configuration is determined both by the flexibility and adaptivity of its constituent parts and the sustainability of the system's goals. This point emphasises the need for any policies which are derived from this schematic to address not only the technological based elements of the problem, but also the policy formulation and control functions. This will involve an interdisciplinary approach, allowing a synthesis of information from a variety of academic fields.

Finally with regard to Figure 2.3, the sub and meta system demarcation is intended to draw attention to the hierarchical nature of the framework. Diversity and adaptability of system components contribute towards the resilience of the system as a whole. Where one decides to draw the system boundaries will obviously influence the focus

of this statement. It is often the case that a particular system module (say a unit of production plant) constitutes both a meta-system (i.e. diversity of its components can promote its own resilience), and a sub system (i.e. diversity of the group of production plant units promote resilience at a higher level). The same relationships can be held to apply to flexibility and adaptability. Hence, there are multiple nested levels of diversity / flexibility / adaptability which can be described for any multiple component system. The complexity of this framework will be shown to restrict the practical application of some of the study's conclusions in Section 10.5.1.

2.9.2 Resilience in technological systems.

Applying these concepts within a technology planning framework results in the derivation of a series of characteristics and attributes that pertain to the physical, configurational and control aspects of a technological system. Taking electricity supply technologies as an example, some key sources of diversity are shown in Table 2.1, together with those environmental variables which they provide resilience against.

Table 2.1 Relationships between sources of diversity and variable factors.

Source of Diversity	Enabling resilience in the face of....
Fuel source	Fuel costs / availability
Plant location	Demand pattern variability
Design life of plant	Technology changes
Output quality	Demand characteristics
Plant scale	Demand pattern variability
Lead time for construction	Changes in construction costs
Energy conversion process	Technology changes

Each of these sources of diversity also provides options for change in the face of general economic, political, social, and environmental turbulence. Designing a technological system that would exhibit these characteristics calls for careful analysis of the behaviour of each element under varying operating conditions. The process of analysis and design in this context is achieved through planning. The following paragraphs review previous research on the attributes discussed above in the context of industrial and organisational theory.

Studies of industrial sector performance have often reflected ecological analogies. The most recent of such studies, (Miles et al, 1993), finds a positive relationship between industry variety and performance, and paraphrases its conclusions thus:

'The beneficial effects of a firm's actions usually cannot be captured by the traditional zero sum view of competition. Instead, a focus on mutual gain requires taking a dynamic, industry level perspective, one in which firms and industries co-evolve. At the heart of such a perspective is the concept of variety.'

In an earlier study Miles & Snow (1986) concluded:

'In order to maintain its long run viability, the total industry must meet the dual objectives of innovation and efficiency, suggesting that there may be an ideal mix of competitive strategies for every healthy industry.'

Identifying the potential benefits of industrial diversity, Prahalad & Bettis (1986) concluded that the limit to the diversity within a firm is primarily determined by the make up of the top management team (a 'soft centred' verdict which will be reflected in the final chapters of this work).

Despite these seemingly positive results, empirical studies of industrial diversity have been hampered by a number of factors relating to the definition of relevant variables, their quantitative measurement, and the expression of their relative effects. Studying the South Wales area of the U.K, Cankling (1963) concluded that whilst there was no statistically significant relationship between the distribution of diversification and unemployment, the general economic security of the whole area had been increased by the introduction of varied new industries. Attaran (1986), in a related study using Shannon's entropy function to measure economic diversity in a study of U.S. industry, found diversity to be negatively correlated with unemployment and found no evidence for a relationship between diversity and either growth rates or economic stability.

In contrast to these two inconclusive studies Grant et al (1988) found diversity and profitability to have a positive relationship although limited by issues of technological and organisational complexity. This study also highlighted the relationship between the benefits of diversity and the extent of environmental turbulence. This topic is explored further in Chapter 8.

Issues of diversity have also been investigated against a background of inter-firm market competition. Such studies are of particular interest here as they represent attempts to explain phenomena that initially appear contrary to microeconomic theory. Mills (1984) found that if demand fluctuations are relatively high, larger firms choose greater flexibility in spite of having to accept a reduction in static efficiency. Of greater relevance to the modelling activities to be reported in the following two chapters however are the findings of Roller & Tombak (1990). Their model showed that product differentiation leads to the introduction of Flexible Manufacturing Systems which, in turn, leads to increased competition across a range of markets, bringing lower prices and profits.

2.10 Summary and conclusions.

The three major themes covered in this chapter concern the role of modelling and modellers, the phenomena of risk and uncertainty, and the interpretation of evolutionary analogies for application to planning and managing technological systems. Modelling has been depicted as both a tool for structuring and interpretation, and as a decision aid. Uncertainty forms the major hurdle to successful planning. A

reassessment of the nature of risk and uncertainty was shown to lead to the emergence of a modified approach to ameliorating their undesirable effects. This approach focuses on issues of flexibility, adaptiveness and diversity. It also aims to engender characteristics and attributes which increase the ability of the system to survive under changing conditions. The findings of Chapters 3-7 will be seen to provide a set of attributes which can be located within the framework of resilience as a strategy. However, as will be shown in Chapter 10, the evolutionary approach to problem solving is most appropriate within specific strategic and decision issue contexts.

Within the context of the subsequent chapters, the terms diversity, flexibility and resilience possess distinct meanings and a brief discussion of their significance and function has been provided. Chapters 3-7 apply concepts of resilience, diversity, flexibility and adaptiveness to problems of technological infrastructure planning and management.

CHAPTER 3

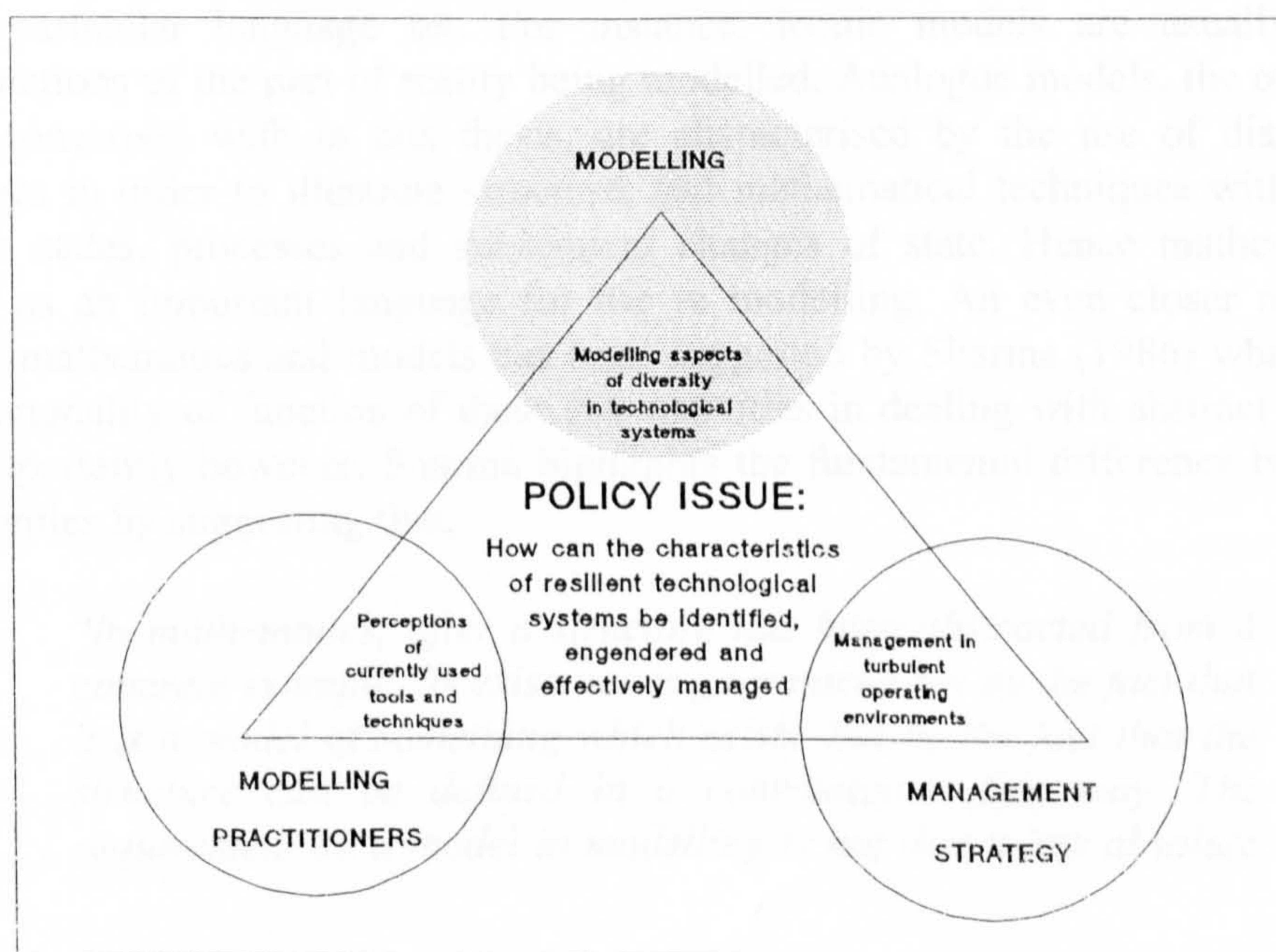
MODELLING THE LONG TERM PERFORMANCE OF TECHNOLOGICAL SYSTEMS: AN INTRODUCTION, LITERATURE REVIEW AND EXAMPLE OF THE USE OF DIVERSITY AS A SYSTEM ATTRIBUTE.

3.1 Introduction

In the previous chapter the various elements of the planning function were reviewed and a revised appreciation of uncertainty was presented. An alternative approach to dealing with uncertainty was outlined based on resilience as a desirable system attribute. This chapter reports the development of two simulation models designed to investigate one element of resilience; that of diversity. Subsequent to the development of a simple spreadsheet model, increased functionality and flexibility is achieved by the model's translation into a programmed version. The issues addressed in this and the following chapter are a particular subset of the more general discussion of resilience presented in Chapter 2. In particular, the type of diversity represented in the models (redundancy), and the context of the studies (technology investment) restricts the applicability of the results and conclusions.

Chapter 2 made clear the importance of modelling as an element of the planning function and drew attention to its multiple character (conceptual / formal etc). The following two chapters address one of these characteristics (the formal), whilst Chapters 5-7 deal with the application of formal models and incongruencies between formal and conceptual characteristics. Figure 3.1 (first presented in Chapter 1) shows where the contribution of Chapters 3 and 4 lie with respect to the overall research programme.

Figure 3.1 Focus of investigation for Chapters 3 and 4.



The perceived importance of modelling as part of the planning function can be assessed by the high level of research effort expended in the development of models and modelling within organisations that engage in technology investment. Specific examples of this can be seen in the electricity supply industry (adopted as the context for the modelling activities reported below), steel industry, water industry, gas, oil etc. Hence, models play an (apparently) large part in technology planning and the critique presented in the first half of this chapter relates to the general form of models in this field as much as to those specific examples used.-

3.2 Modelling uncertainty and resilience in technological systems.

Before reporting on the development of and results from a model designed to investigate the role of diversity in technological systems (Section 3.3 below) it is appropriate to provide some background to the modelling process. The following subsections address issues relating to generic modelling activities and seek to emphasise the difference between the two approaches to handling uncertainty which are compared in Figure 2.2..

3.2.1 Some comments on the limits to modelling

Whilst criticism of modelling processes has enjoyed a period of high productivity in recent years (see Kempis, 1991 for a definitive and contemporary review), applied exemplary studies are less common. However, many writers have drawn attention to the problems of language and simplification. The language of a model refers to its method of representation and, whilst some tools are adept at providing one type of representation (i.e. structural, quantitative, qualitative), there are problems in isolating a language which can effectively cope with more than one type.

As mentioned in Chapter 2, models can assume many forms, each of which is associated with a particular language set. For instance, iconic models are usually physical representations of the part of reality being modelled. Analogue models, the ones we are mainly concerned with in this thesis, are characterised by the use of diagrammatic techniques in order to illustrate structure, and mathematical techniques with which to illustrate states, processes and subsequent changes of state. Hence mathematics has evolved as an important language for use in modelling. An even closer relationship between mathematics and models has been suggested by Sharma (1986) who identifies the commonality of function of these two activities in dealing with abstract structures. More importantly however, Sharma highlights the fundamental difference between the two activities by suggesting that;

"In mathematics, after a structure has been abstracted from a concrete example, its existence is guaranteed not by the fact that it is a model of something which exists, but by the fact that the structure can be defined in a contradiction free way. The requirement on a model in modelling is not that it has absolute

freedom from contradictions. The philosophy behind modelling is pragmatism rather than a search for the absolute truth."

Applying this distinction to the use of mathematics in the modelling process provides a template for assessing the relevance of the former to the latter for any given system type. Mathematics has been hugely successful as a language for describing and analysing physical systems but less so in the fields of psychological, behavioural, and social inquiry. Consequently, investigations which focus on systems which contain a mixture of physical and behavioural elements are faced with some obvious dilemmas. Perhaps the most important of these being that no opportunity is allowed for qualitative changes to the system under consideration. This may involve changes in the structure of the model itself or alterations to utility criteria and relationships between variables. If such changes were to be accounted for in a model, the language of mathematics would have to be replaced by a far more dynamic and less structured notation which could allow for novel and unforeseen actions. Recent developments in Set Theory (the use of 'fuzzy sets' for instance) constitutes a contribution to the development of such a language. However, it still maintains a reliance on mathematical principles, the very nature of which act to restrict the types of relationship which can be analysed.

Scope for the development of an alternative language set for representing both structure and process contained within conceptual and formal models is limited by our perception of the world and our communicative capabilities. This has not however prevented research in this area, particularly in the fields of Multiple Criteria Decision Analysis and Expert Systems. (Schneeweiss, 1987; Tsoukias, 1991).

The above cited arguments make for a strong critique of the use of mathematics as a modelling language. These censures can also be levelled at the use of computers in modelling. The fundamental nature of computing operations (binary mathematics) creates boundaries to the use of computer stored structures and programs as representations of techno-economic processes.

Although representing a powerful critique of modelling per se, the above points do not invalidate the use of mathematics and computers as tools for investigation and learning. What is imperative is that the limitations of models be recognised and their subsequent application informed by such awareness. The literature on modelling methodology has addressed these problems and provided some guidelines for prospective modellers to follow. In a paper relating to large scale urban models, Lee (1973), makes some pertinent comments concerning the effectiveness and limitations of modelling. His 'seven sins of large scale models' identify those factors which, either in isolation or combination, serve to undermine the validity of many models. The modelling activities which are described in the following chapters largely fulfil Lee's three guidelines for model building:

- 1) A balance is needed between theory, objectivity and intuition.
- 2) Start with a particular policy problem which needs solving, not a methodology which needs applying.
- 3) Build only simple models.

Although the criticisms of modelling outlined above are serious and, in part, irrefutable, they define a boundary to the application of the model findings rather than a boundary to their development and use. It has been noted earlier (§ 2.2.1) that models are a ubiquitous mode of conceptualisation, indeed possibly our only mode. Hence, it is quite appropriate to investigate the boundaries of this tool and identify its failings and limitations. However, it does not necessitate a complete withdrawal from formal modelling activities. Additionally, and as will be seen below, modelling can be put to uses which aid the identification of generic structures and configurations, the utilisation of which is not dependent on the mathematical accuracy of the model but on the representation of systemic attributes and relationships. The following section provides an interpretation of the role of model validation, with reference to the relevant literature, which supports the modelling activities described in the latter part of this chapter.

3.2.2 Model validation:

One specific class of model is of particular relevance to this study; that of simulation modelling. The relevance of this type of model to the problem set outlined in Chapter 1 is that it allows the relationships and dynamics of a system to be represented and studied. There are several contentious issues surrounding the use of simulation modelling, including those of representation and predictive capacity. It is therefore pertinent at this point to discuss the nature of the simulation models to be used in this and the following chapter.

Simulation models can generally be described as an experimental and applied methodology which seeks to:

1. Describe the behaviour of the system.
2. Construct theories or hypotheses that account for the observed behaviour.
3. Use these theories to predict future behaviour.(Shannon, 1975)

Whilst this typology provides some guidance as to the role of simulation modelling it is restricted by its linear approach to problem solving. Of more relevance to the models developed in this and the following chapter is a more generalist view of simulation as '*an attempt to model the behaviour of a system in order to study its reaction to specific changes.*' (Chen & Kachka, 1974).

As noted in Section 3.3.4 the models presented here are not predictive in nature. Indeed the modelling activity is informed by the work of several authors who have identified major problems with attempts to simulate systems that exhibit any level of unpredictable behaviour. The ramifications for model testing suggest that '*where there are irreducible uncertainties, prediction is no test at all of a model's validity.*' (Boulding, 1982).

With respect to the models which are presented in the following sections it is therefore important to remember that the objective of analysis is to investigate the interactions and behaviour of those variables included. As noted above, the modelling of resilient characteristics in economic and industrial systems is a relatively new area of research. Consequently, of greater relevance are the comments of Schrank & Holt (1967) who propose that:

'...the criterion of the usefulness of the model be adopted as a the key to its validation, thereby shifting the emphasis from a conception of its abstract truth or falsity to the question of whether the errors in the model render it too weak to serve the intended purpose.'

As a background to the modelling activity, two streams of previous research are of interest; the literature on planning in the Electricity Supply Industry (ESI), and that concerning the use of evolutionary analogies in planning technological systems. Each of these is reviewed respectively in the following two sub-sections.

3.2.3 Review of planning models used in relation to the ESI.

Initial work on the problem of investment in the ESI involved the application of a number of techniques including mixed-integer programming (Gately, 1970, Ammons & McGinnis, 1985), linear programming (Bessiere, 1970; Kok & Oostvoorn, 1986), dynamic programming (Borison, 1982), stochastic models (Giglio, 1977), and Scenario Analysis (Lootsma et al, 1990).

The most influential attempt to systematically address the investment problem with regard to electricity generation expansion was undertaken by Anderson (1972), using a linear programming approach. The least cost model which he developed also became a generic analysis tool for sequential investment in large scale technologies. However, in more recent years least cost planning has been re-evaluated in the light of the increased need to take account of a widening utility set which includes environmental, social and safety criteria. Survey results from the USA also indicated that risk and uncertainty were becoming an increasing concern amongst decision makers (Hayes & Scheer, 1987).

Considerations of uncertainty regarding ESI planning continued to attract wide attention in the 1970's and 1980's (Baughman & Joskow, 1974; Stover et al, 1978). Alternative methods for representing uncertainty were developed at this time including the use of probability distributions. However, some studies showed that under general conditions simple linear programming could provide the same optimal investment solution as a more complex stochastic program (Murphy et al, 1982).

One of the effects of demand and other uncertainties in the ESI is the influence of irreversibility. Long lead times in generation unit construction means that changes in key cost or demand variables can result in a situation where the station operator is forced to either abandon the project or accept high operating costs. It has been shown,

using a dynamic programming model, that shorter lead time technologies can be beneficial in these circumstances although the magnitude of advantage is dependent upon both fixed and variable cost functions (Boyd & Thompson, 1980). This area of research has also been addressed using a simulation modelling approach (Ford and Yabroff, 1980; Ford & Youngblood, 1982).

Uncertainty regarding reliability parameters has also been an issue in ESI planning, Bloom (1983) developing a decomposition model to solve the problem for a general case. A similar approach has been used to analyse uncertainties due to fluctuations in cost functions (Borison et al, 1984). Supporting work in this area has included a decision tree approach to analysing the sensitivity of the planning process itself due to uncertainty surrounding the accuracy of forecasts (Hobbs & Maheshwari, 1990). The influence of uncertain demand with regard to the timing of transmission line investments has also been addressed (Martzoukos & Teplitz-Sembitzky, 1992)

An attempt to take a wider perspective on the planning problems associated with project selection for the ESI was taken by Merril et al (1982) by addressing the relevant strategic issues. Focusing on the trade offs and trends evident in the planning problem, this paper introduced a new ethos into the literature; one of learning tools. More recently there have been attempts to combine a number of competing methods (Dapkus & Bowe, 1984; Mo et al 1991), and to apply emerging methods and techniques such as expert systems (Farghal et al, 1988), and a fusion of expert systems and dynamic programming (David & Rong-da, 1989). Despite these efforts to broaden the perspective of planning in the ESI, very little work has been carried out which specifically adopts ideas of resilience (the exception being the mainly theoretical contributions of Odum [see below]). Therefore, the modelling activities reported in this and the following chapter are novel in the sense that they constitute a fresh approach to the problem of planning technological infrastructures.

3.2.4 The use of evolutionary analogies in planning research.

The modelling methodology utilised in this thesis is of primary importance to its contribution and represents a direct attempt to expose a new approach to dealing with uncertainty in planning technological infrastructures. In order to provide an introduction to this type of modelling activity, this section reviews some of the related work to be found in the literature.

As mentioned in the previous section, diversity plays a key role as a '*fundamental and permanent characteristic of industrial environments undergoing technological change.*' (Silverberg et al, 1988). However, there have been few previous attempts to adopt ecological analogies to aid either system conceptualisation or practical analysis in the context of energy system planning. The most influential study to address this problem area was that carried out by Odum, H.T. (1973) which, whilst being focused on the energetics of system dynamics, drew attention to the need for diversity as a source of flexibility:

'In ecosystems, diversity of species develop that allow more of the energies to be tapped. Many of the species that are specialists in getting lesser and residual energies receive subsidies from richer components.' (Odum, H.T. 1973)

In what represents a key paper in relation to this thesis, Odum, E.P. (1975) identified too much diversity as being as debilitating as too little. (As was also found in some of the strategic management research reported in Section 2.9.2). An extended quote from this source could serve as a problem formulation for the modelling activities reported in the following sections.

'Our general theory may be irrelevant to man's fuel powered civilisation. If we consider energy sources as very important 'species' then the developed countries of the world are now in the very low diversity category with 90-95% dependence on fossil fuel.....Now the problem is how to avoid the 'bust' as this major source declines.' (Odum, 1975).

The study goes on to use Simpson's diversity index to analyse the potential for diversifying the technology base for primary energy production.

A particularly interesting extension of this approach is that reported by Bodger et al (1989). Reporting on a dynamic model of industrial society which suggests that different energy forms compete in a '*struggle for survival*', they posit that:

'society appears to have little choice in the long term development (of primary energy technologies); political leadership and economic management can only strive to remove the perturbations from these trends which cause such disruptions to people's lives.'

Management Science has addressed issues of diversity and flexibility, particularly in relation to environmental turbulence. The resultant approach to modelling is typified by Tomlinson (1989). Speculating on a range of possible constructive approaches, Tomlinson asks how models can be used to '*determine the principles that will enable us to develop effective, flexible organisational structures and procedures for organisations to survive in a turbulent environment.*'

Although broad theoretical propositions such as those reported above suggest that there may be benefit to investigating the role of diversity, flexibility etc. in providing resilience in technological systems, there has been little advance in determining the key attributes of such systems. A scarcity of research in this field is somewhat perplexing given the evidence in the strategic management literature (reviewed in § 2.9.2) for a tentative relationship between diversity and some measures of resilience and stability. One of the purposes of this thesis is to contribute to the identification of those techno-economic attributes which might engender resilience and stability.

Technology planning essentially concerns the decision to invest in the development or utilisation of a specific tool, process or product. Within the context of this part of the study, the term relates to the analysis of a range of process systems within a utility industry setting. The assessments reported below aim to formalise of the various cost functions associated with each technology and the application of these functions to a framework which describes their relationships both with each other, and with other elements of the system. A simulatory approach is used, the models being intended as an exploratory tool for developing insights to the issues described above.

Given the lack of any previous notable studies on the technological (or technological system) attributes of sustainability, there is a need to identify candidate attributes for inclusion in the model. Diversity, flexibility, adaptiveness, and resilience can be promoted in technological systems in a number of ways, including;

Design of technology.

Technology design can enhance the resilience of the system by ensuring that options for future action are not restricted by current attributes. In addition there will be a series of more qualitative features of the technology which may be dictated by considerations of resilience from a different perspective (i.e. environmental, political etc.). The type of design considerations which will enhance resilience may include the use of a modular design approach. Such an approach is typified by a broader consideration of the design parameters, allowing for the utilisation of components in more than one setting and ensuring that the life-cycle of the plant's major components does not dictate the useful life of other elements of the plant. Consideration of the life-cycles of the raw materials as well as the components themselves can also bring benefits through recycling and waste component reuse.

Scale considerations are also an important factor in determining the resilience of a technological system and is closely linked to the network aspects discussed below. It is erroneous to assume that by scale issues is meant small scale, the relevant issue is rather concerned with appropriate scale dependent upon technology type and other factors. Life-cycle considerations can also influence the resilience of a system as the interactions between different component, sub system and system life-cycles creates opportunities for change and adaptation.

Design of network characteristics.

The design of network characteristics is focused around both spatial and structural aspects, resilience resulting from the potential for additive or distributive flexibility.

Investment policy.

Investment strategies can exert a major influence on resilience as project timing, size, and level of commitment determine a measure of exposure, both financially and organisationally (resources etc.). Diversity of project attributes is a key feature of an investment strategy focused on resilience, allowing risk to be spread and learning processes to be engaged in without over commitment.

Operational management.

Operational management concerns the day to day running of plant. Resilience at this

level is promoted by a careful matching of skills and knowledge to processes and tools without too strong an emphasis on regulation or formal practices.

Selection of raw material sources.

Finally, the selection of basic resources such as fuels or raw materials can greatly influence levels of resilience. Again, diversity and the potential for change are key attributes when considering this issue. It should be remembered that perhaps the most important determinants of resilience concern the organisation or institution itself. Hence, sustainable organisational goals and structures are key elements of a resilient system.

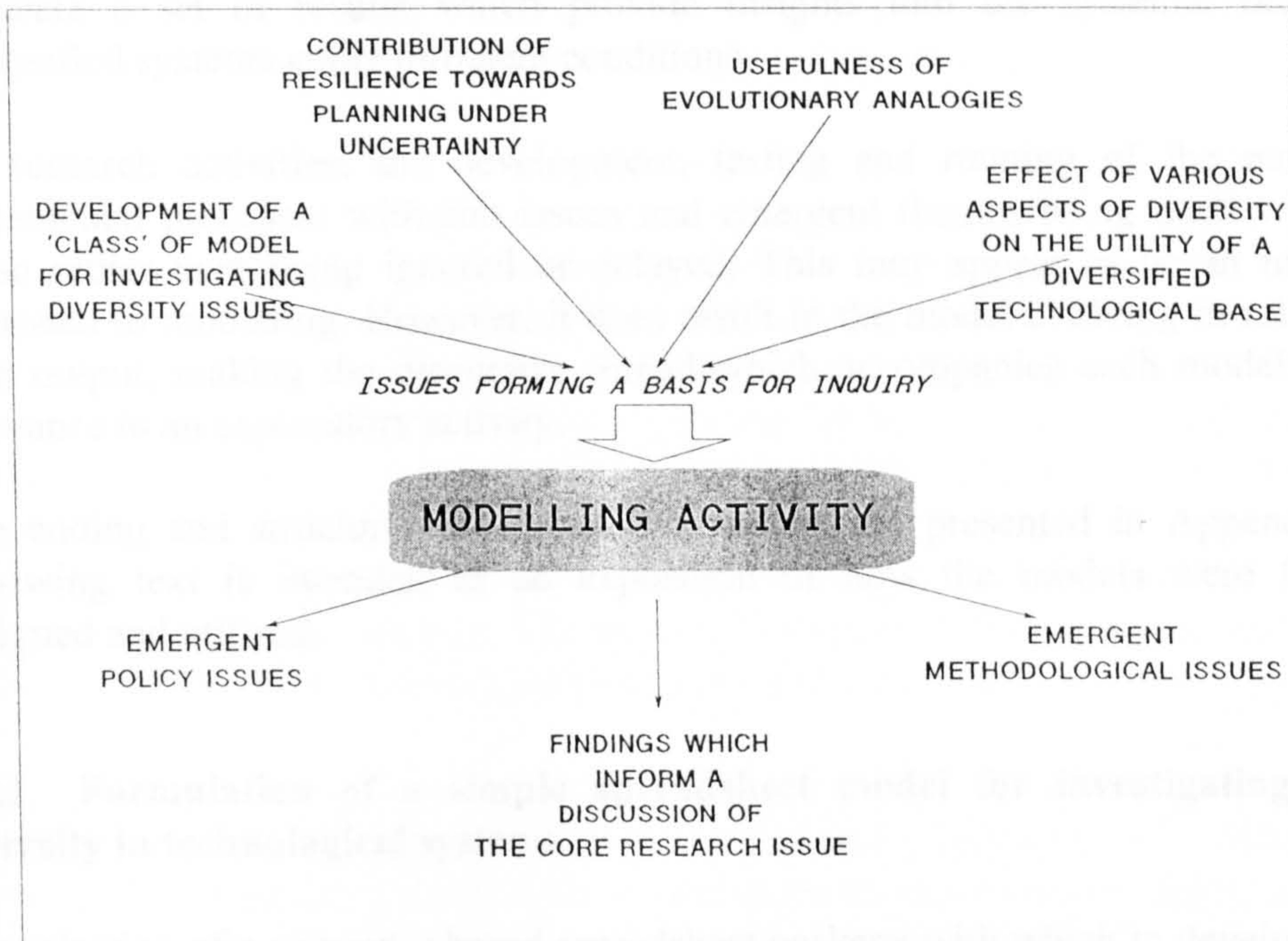
In summary, the models developed in this and the following chapter are informed by the critiques of Ackoff and Lee and motivated by the comments of Odum, Holling, and Rosenhead. The generic modelling technique is simulatory in nature and is therefore part of a large group of models which are well documented. However, the application of evolutionary analogies to techno-economic systems as modelled in the form presented below, is not found in the literature. Hence, guidance on issues of model structure and validation are scarce, necessitating an awareness of the exploratory nature of the model. This means that the model's results will provide at best an indication of potentially beneficial areas for further analysis. In other words, the modelling activity is investigative and tentative rather than predictive and exhaustive. There is an increasing role for such 'learning' models which move away from prediction towards experimentation, and through experimentation, towards learning, (de Geus, 1992).

3.3 Modelling resilience: The development of a simple spreadsheet example.

As discussed in Chapter 2, an alternative approach to addressing uncertainty can be developed from a reconsideration of the nature of uncertainty and the subsequent adoption of evolutionary analogies. Such a change of approach emphasises the role of resilience through diversity, flexibility and adaptiveness. Whilst the theoretical work on such an approach to planning has been widely covered, there has, as yet, not been a similarly intense effort to apply any modelling techniques to example problems.

The intent of this section is to develop and explore the bounds of such a model as applied to the issue of technology selection. The models developed are of two types. Firstly, a spreadsheet based investigation into the effects of various parameters on the total cost of an investment strategy characterised by two technologies is presented. Secondly, a more detailed, computer programmed model (using the 'C' programming language), is used to examine the effects of cost and scale factors on total costs for a similar type of technological system. Figure 3.2 (overleaf), presents a mapping of the model's use in relation to both the broad concerns of the thesis and the emergent issues covered in previous chapters.

Figure 3.2 Mapping of major themes onto the modelling activity.



Each of the issues which form a basis for enquiry in Figure 3.2 have been addressed and reviewed in Chapters 1 and 2. The emergent functional and methodological issues are to be discussed in Chapters 8 and 9. However, the main thrust of the modelling activity's conclusions will be to inform a discussion of the issues raised in the foregoing text. This is a process which continues iteratively through this and the following chapter, allowing the model to evolve in response to both its own output and the broader dynamics of the problem area.

The models which are developed over this and the following chapter have two roles. Firstly as the nuclei of decision support tools for use in strategy formulation and secondly as learning tools for the investigation of specific phenomena. Any application as a decision support tool will require the presentation of a robust set of simulation results and a comprehensive defence of the validity of the models structure and relationships. However, whilst a number of general conclusions regarding possible strategies resulting from the model's output will be presented, the development of a decision aid is not the main objective of the modelling activity.

The latter of the two roles itemised above is described by Phillips (1982) as being the development of a *'framework for thinking about the problem, for exploring the consequences of different assumptions.'* Phillips sees the problems associated with decision analysis diminishing if decision theory is viewed as providing a framework for the iterative development of a coherent representation of the problem. It is within the

bounds of these comments that the major contribution of the modelling activities should be interpreted. The intention is to address the principal phenomena introduced in the previous two chapters and to characterise and simulate their interrelationships. This will generate a set of results which provide insights into the systemic behaviour of diversified systems under turbulent conditions.

As research activities, the development, testing and running of the models were incremental processes with sub issues and emergent themes being dealt with as they arose rather than being ignored or delayed. This may appear to be an unstructured approach to modelling. However, it does result in the model evolving in relation to its own output, making the discursive thread which accompanies each model of greater relevance to an exploratory activity.

The coding and structural details of each model are presented in Appendix 1. The following text is intended as an exposition of how the models were formulated, designed and utilised.

3.3.1 Formulation of a simple spreadsheet model for investigating issues of diversity in technological systems.

The selection of a computer based spreadsheet package with which to develop an initial model was prompted by two considerations. Firstly, the demonstration of many of the issues central to the modelling activity do not require the development of an elaborate model. This is true regarding both the theoretical exposition and the formal structuring of the problem. Secondly, spreadsheet models lend themselves to exploratory processes, being easily constructed and open to alteration and expansion without large scale disruption to the model structure. Additionally, the use of such models within a "windows" operating environment allows both analytic, functional and graphical elements to be viewed and manipulated simultaneously.

The investigative aims of the activity are centred around an examination of the system's performance rather than the isolation of optimal strategies under given conditions. Additionally, the simplicity of the problem formulation allows a broad range of issues to be addressed in a constructive way. As a measure of utility, a cost based approach is used so as to enable comparison of system performance under different operating environments. These environments are represented by a variety of cost factors including capital, operating and maintenance elements.

The spreadsheet simulation model allows the analysis of a strategy which could be loosely termed resilient over one which reflects optimisation. A two technology scenario is adopted as the basis for analysis, each technology possessing its own capital and operating cost functions (see Appendix 1 for details). Two strategies are compared with each other. The first strategy is represented by a scenario where a decision is taken to invest in only the technology with the lowest total costs in any one year (the 'Single Technology Strategy'). This represents a strategy who meets 100% of demand with a

single technology. The second strategy, involves an investment of less than 100% of the lowest cost technology, the difference being made up with a second technology (the 'Two Technology Strategy'). Diversity is thereby represented by different types of plant being operational at the same time. The results illustrated below reflect the variation in costs accruing to the two types of strategy under identical cost conditions.

At some time in the future the operating cost function for the initially cheaper technology undergoes a shift to a higher cost regime, relative to the initially more expensive technology. At this point the Single Technology Strategy switches full capacity to the now cheaper technology whilst the Two Technology Strategy simply 'tops up' with an additional x% of the cheaper technology. In effect, this reflects a second investment event which may conform to an increase in total capacity, an equipment replacement programme or a response to the changes in relative costs.

Lead time considerations are allowed for by including an (initial) 3 year investment time frame at each investment event. The variables included in the model and utilised during the analysis in addition to the capital and operating cost parameters include;

Discount rate: The influence of discount rates on the temporal accrual of costs and benefits for any particular project is well documented (Dasgupta, 1972; Mishan, 1982). The inclusion of a discount rate in the model calculations allows the opportunity cost of capital to be considered if required.

Learn factor: One of the arguments used to support the generation of diversity within technological systems is that concerning an increase in knowledge. This proposition suggests that designing and building plant acts as a knowledge acquisition process, enabling future operations of a similar kind to be undertaken at reduced cost and with greater confidence. As an element of diversity, this factor is rarely addressed (however, two related studies can be found in Cukierman, 1980; and Bernanke, 1983). Despite this, learning and acquiring knowledge regarding feasible technological configurations enables improvements to be considered to future, planned systems. Furthermore, the experience of construction and operation will often allow the contribution of the individual technology to the whole system to be evaluated. Hence a learn factor is included in the analysis to allow for repeated investments in similar technologies to be undertaken at a cost saving compared with earlier implementations.

Cost ratios: The relative magnitudes of capital and operating costs both within and between the two technologies are representative of a cost function envelope, the state of which through time can be manipulated to reflect a range of conditions. Although the actual values used for the various types of cost are arbitrary their relative proportions are similar to those found within many utilities such as the electricity supply industry. (Ref: Handbook of the CEGB 1979-90)

Total costs are utilised in the model for two purposes. Firstly as an indicator of relative utility and secondly as a comparative measure of the extent to which the investment and operating elements of the organisation's cost profile affect its performance. A

technology's or organisation's cost profile relates to the temporal trends in cost elements which accrue as a result of technology operation. These may include labour costs, fuel costs etc or be aggregated in the form of capital and operating costs. (The models presented below only deal with a restricted set of aggregated cost profiles). The results from the spreadsheet model presented in Section 3.3.3 will show that the ratio describing a relationship between capital costs and operating costs is a significant indicator of a technology's ability to operate efficiently as part of a diversified technological system. In particular this ratio should determine the relative benefits of different technologies with varying cost profiles.

Operating cost shift: This parameter reflects the magnitude of the shift in the operating costs of Technology #2. This represents a situation where the operating costs of one technology undergo a transition to a higher regime. Determining factors for such a transition could include supply / demand shifts in key process materials, changes in fuel or labour costs or the imposition of selective taxes on elements of the technology's process feedstock. The occurrence of this cost shift is used as the progenitor of a second technology investment sequence with the initially more expensive technology becoming less costly.

Level of investment in alternative technology: This represents the amount of Technology #2 (as a percentage) invested in by the Two Technology Strategy in year 1. Instilling a measure of diversity in the technological system by investing in an alternative (but originally more costly) item of plant constitutes the core resilience characteristic of the model's configuration. By investing in two technologies, the Two Technology Strategy accrues additional costs in the years before the price transition and is penalised for holding over-capacity. This factor determines the level of investment in the alternative technology set.

Lead time: The number of years taken for an investment programme to be completed. Lead time issues in technology planning have been a central concern of research over many years. In the particular case of the electricity supply industry, Boyd & Thompson (1980) and Hirst (1990) investigated the effects of short and long lead-time power plants, finding that the trade-offs involved on a cost reduction basis were complex and not always reducible to the timing of build operations. The study described below differs somewhat from these and other related models in that an optimal plant construction programme is not the objective. Additionally, the strategy element of the simulation is proactive rather than reactive in form. However, as will be shown in Chapter 4, Hirst's conclusion that

"these benefits (reduced costs) are a function of the relationship between construction time and prior recognition of the new load, the uncertainty about when new loads will appear, and the relationships among the prices at which the utility can buy and sell power to others" Hirst (1990).

correctly identifies the complexity of this problem.

Cost hike time: The year in which the rise in operating costs of Technology #2 takes place. The timing of this cost transition is used in the model to analyse the trade-offs between the costs of diversity (as represented by redundancy), and the benefits of flexibility (as represented by a less costly second investment sequence).

Cost hike rate: Reflects the number of years over which the hike in the operating costs of Technology #2 occurs.

The base case conditions for each of these factors were as follows:

Discount rate = 5%

Learn Factor = 0.6

Operating Cost Shift = 1600

Level of investment in Alternative Technology = 50% of Technology #1

Lead Time = 1 year

Cost Transition Time = Year 10

Cost Transition Rate = 1 Year

Each of the above itemised elements were utilised to investigate the overall behaviour of the system as measured in terms of the total cumulative discounted costs of the Single Technology Strategy minus that for the Two Technology Strategy. In analytic terms, this function can be represented by:

$$\frac{TC1n}{(1 + DR)^n} - \frac{TC2n}{(1 + DR)^n}$$

Where:

TC1n is the Single Technology Strategy's costs for year n.

TC2n is the Two Technology Strategy's costs for year n.

DR is the discount rate.

This broad comparative measure is used as the y axis unit on Figures 3.3 to 3.12 (below), and represents the nett benefit of the two technology strategy over the single technology strategy.

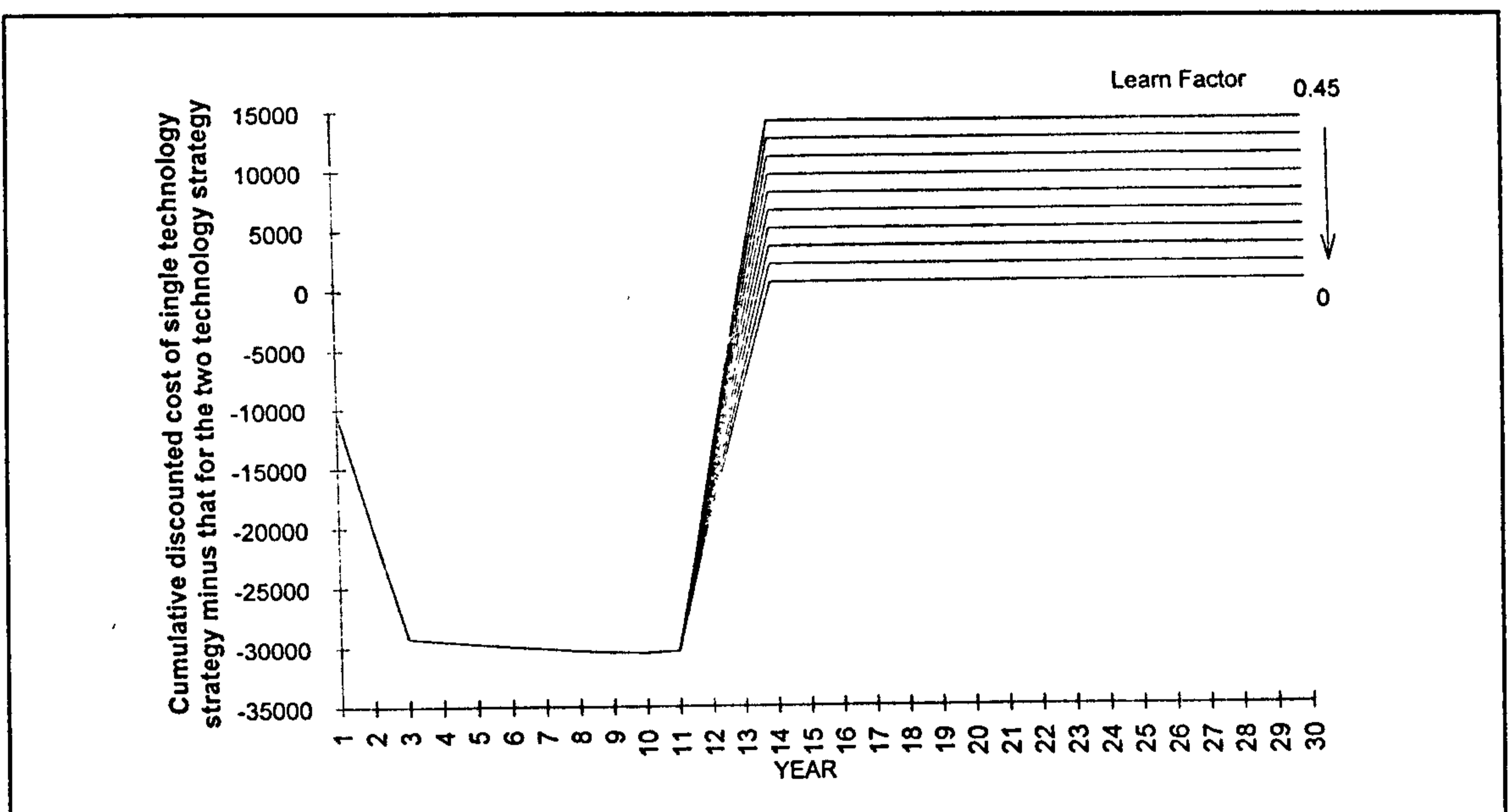
3.3.2 Model output and discussion of results.

Placing the output from the spreadsheet model in the context of the thesis as a whole can be carried out at two levels. Firstly, the results obtained are relevant to a broadly based discussion of technology investment policy. Secondly, the use of the model expands the debate concerning the usefulness of this type of model for this particular application. In particular, the links between investment analysis and broader issues of technology

policy can be drawn out and analysed as a result of the model's use.

As noted in Section 3.3.2, a key parameter and supporting factor in discussions regarding diversity generation as a desirable technology strategy is that of learning. It is posited that diversity of technological attributes enables knowledge to be gained regarding the performance and behaviour of the technologies and configurations concerned. As a result of this, future applications of the technology can be carried out more efficiently. This knowledge acquisition effect is obviously only relevant if secondary investment events occur (Figure 3.3). Furthermore, the magnitude of associated cost savings accrue incrementally as a function of both the level of learning and the time period over which secondary use occurs. Figure 3.3 depicts only the case in which savings are made during construction. The learning factor represents the percentage reduction in construction costs accruing as a result of a previous 'build' operation.

Figure 3.3 The influence of learning on the utility of a diversified technological base.



Variations in the capital and operating cost ratios for each technology type influence both the potential for and magnitude of, any benefits which are associated with a specific investment policy. As the relative capital cost of Technology #1 increases, so the Two Technology Strategy justifies a greater spread of its portfolio across two technologies (Figure 3.4). Conversely, as the capital costs of Technology #2 rise, the Two Technology Strategy is committed to increasingly higher penalties for adopting a measure of this technology prior to the rise in operating costs (Figure 3.5).

Figure 3.4 The influence of the capital cost of an initially cheaper technology on the utility of a diversified technological base.

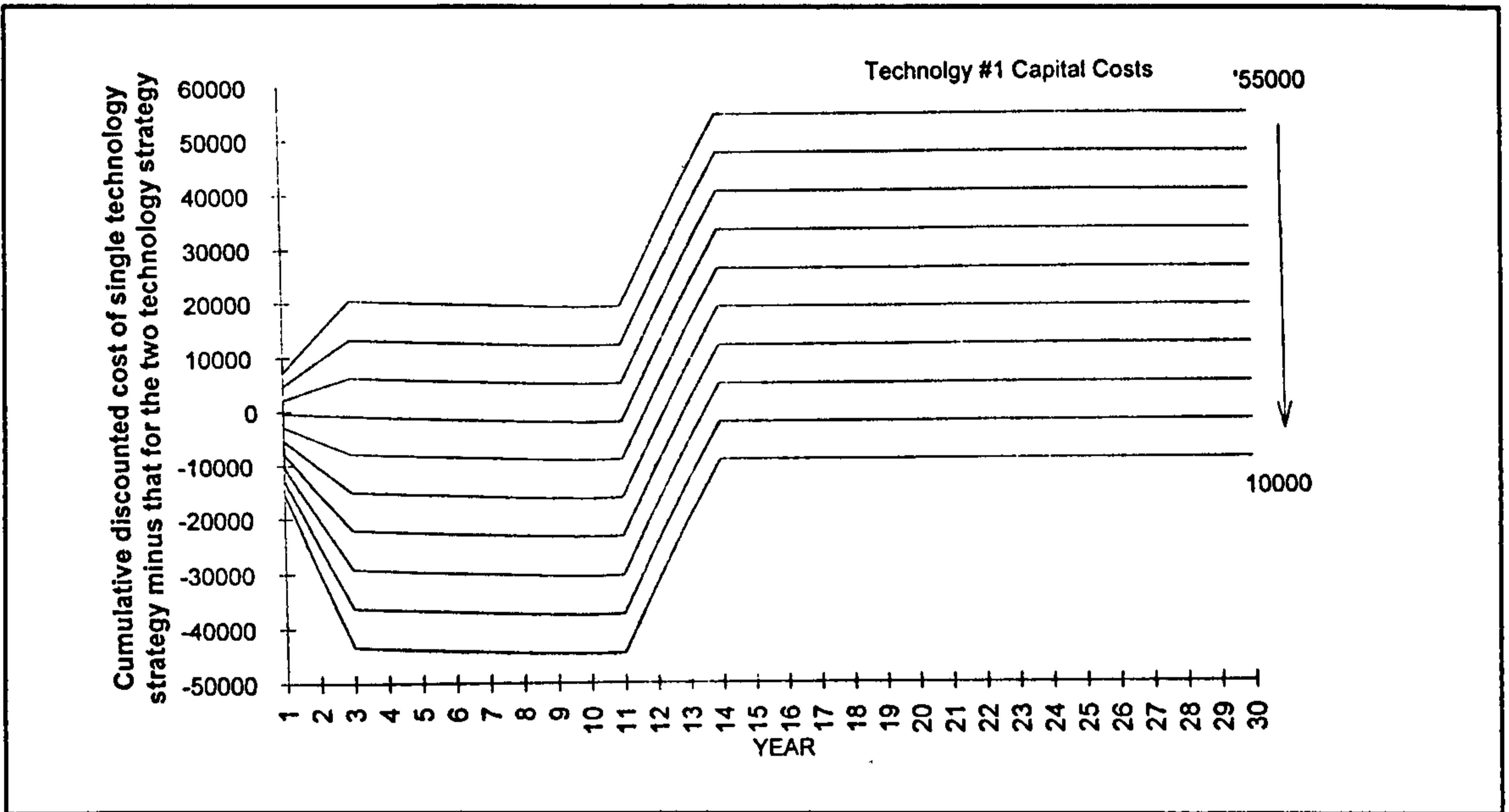
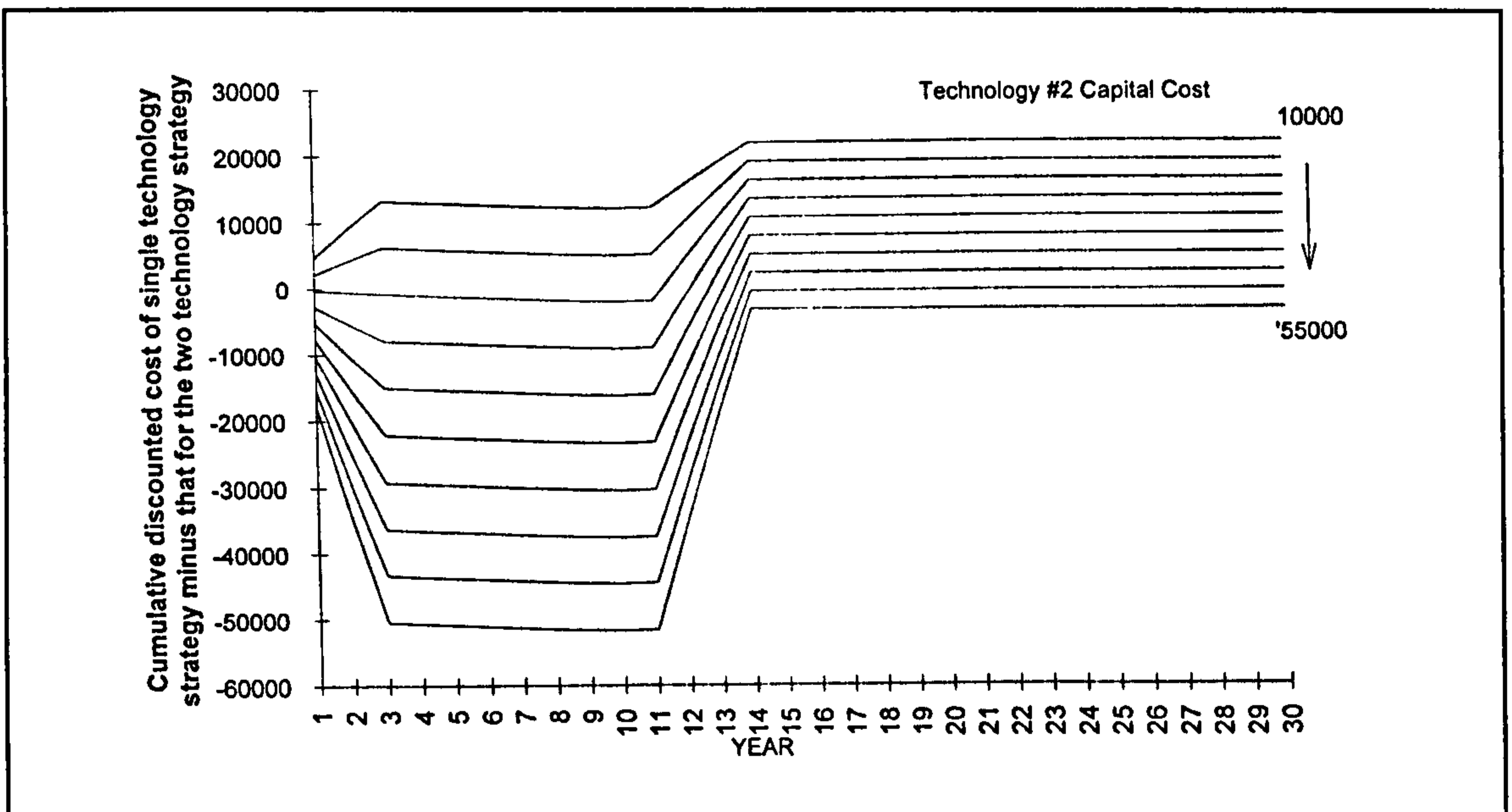
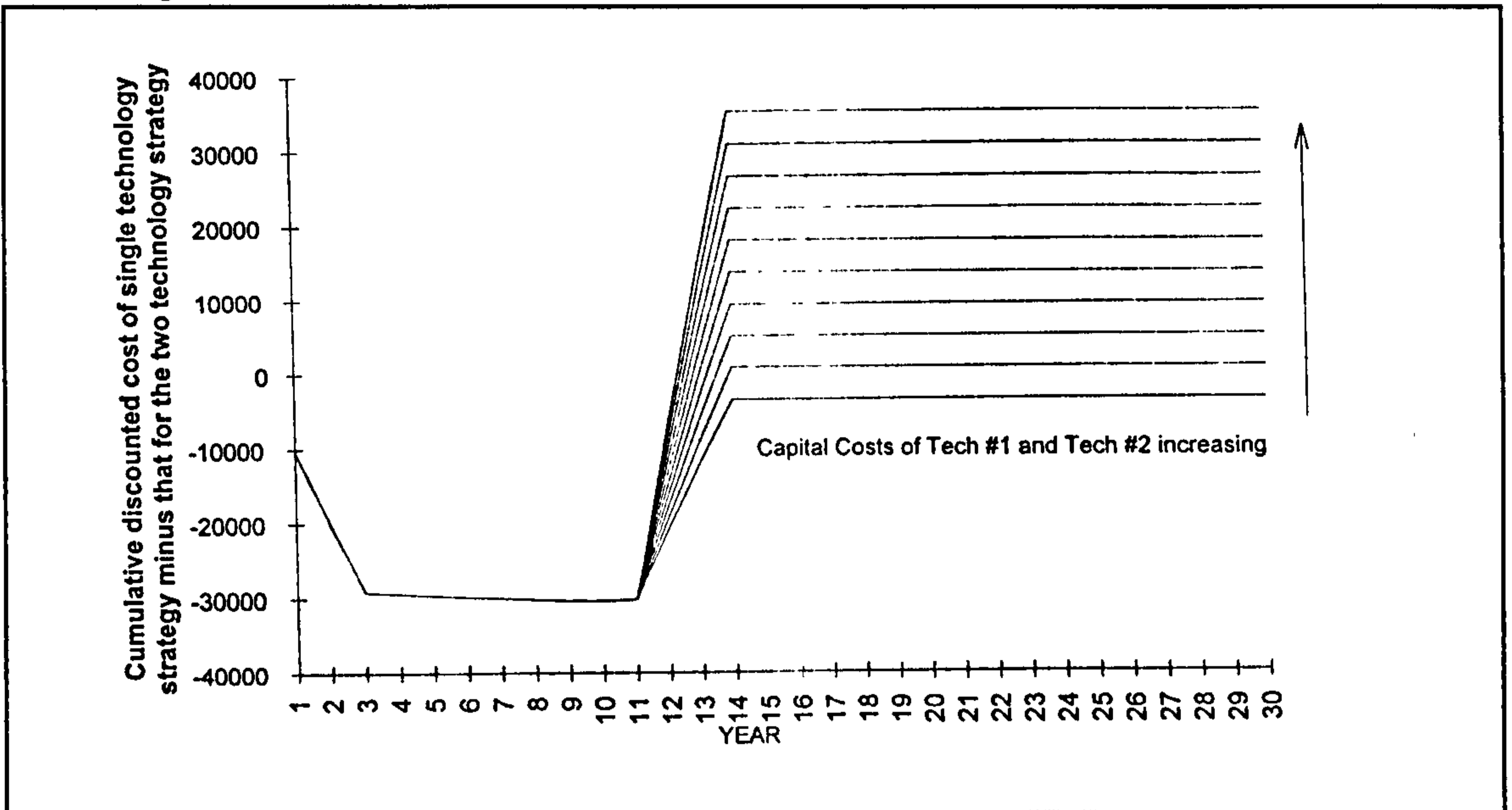


Figure 3.5 The influence of the capital cost of an initially more expensive technology on the utility of a diversified technological base.



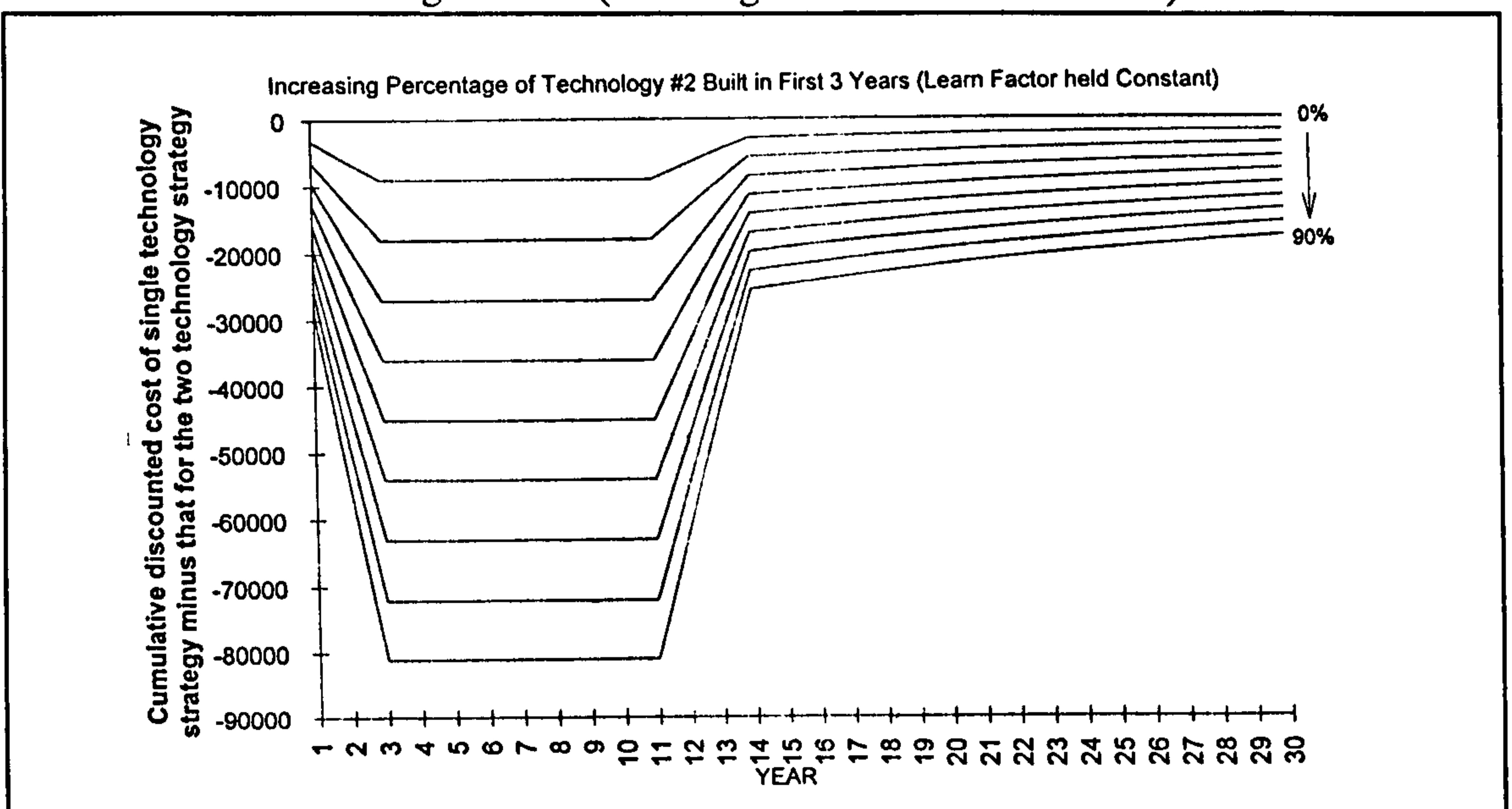
Given a situation where the ratio of the capital costs for the two technologies remains constant but their absolute value increases, the Two Technology Strategy makes increased savings as a result of the learning factor (Figure 3.6).

Figure 3.6 The influence of capital cost ratios on the utility of a diversified technological base.



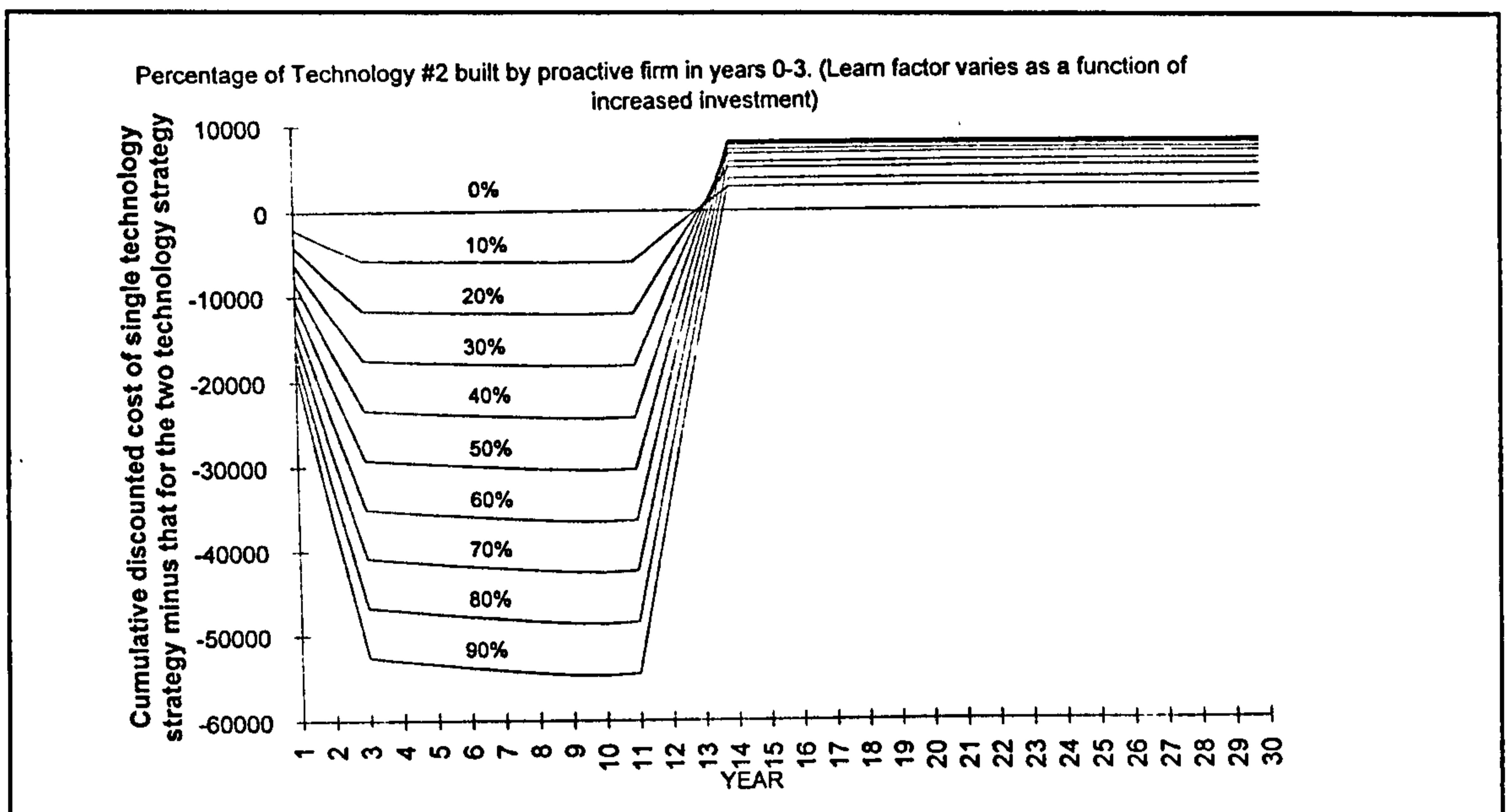
The relationship between the level of investment in an alternative technology and the associated learning factor is obviously one of importance. This is particularly the case when considering the possible effects of an investment policy centred on diversifying technological attributes. Under the base conditions reviewed in the previous section, and with the learning factor held at 0, the effects of increased investment in the alternative technology for the Two Technology Strategy are counter-productive (Figure 3.7).

Figure 3.7 The influence of increased investment in a second technology on the utility of a diversified technological base (Learning factor held constant at 0)



However, if the learning factor reflects the level of investment (i.e. higher levels of initial investment lead to greater reductions for secondary investment events), the results show a different trend (Figure 3.8). Here, whilst building and operating 50% of Technology #2 from year 0 is relatively costly before the change in cost regimes, it results in the most benefit after the change. Deviations from a 50% initial investment in Technology #2 results in either too heavy a penalty being incurred before the price hike (an over investment in Technology #2 in years 0-3), or after the price hike (an under investment in Technology #2 in years 0-3).

Figure 3.8 The influence of increased investment in a second technology on the utility of a diversified technological base (Learning factor associated with level of investment in second technology).



Changes in the form and nature of the cost regime change also affect the relative benefits of the Two Technology Strategy over the Single Technology Strategy. Increasing the magnitude of the regime shift results in the Two Technology Strategy being more beneficial (Figure 3.9), whilst delaying the change results in the Two Technology Strategy having a greater margin of loss to recoup (Figure 3.10).

Figure 3.9 Influence of increased 'price hike' for initially cheaper technology on the utility of a diversified technological base.

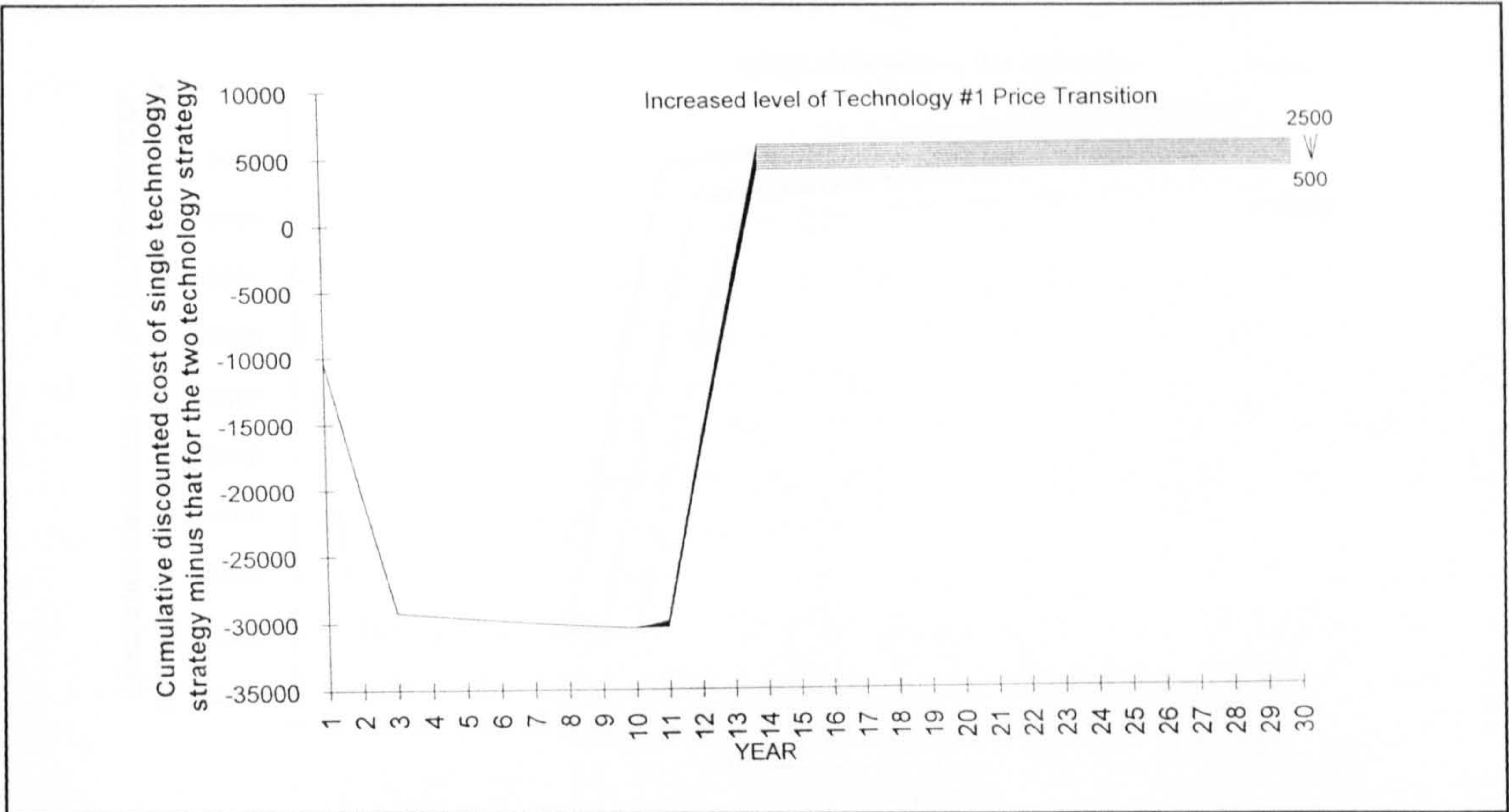
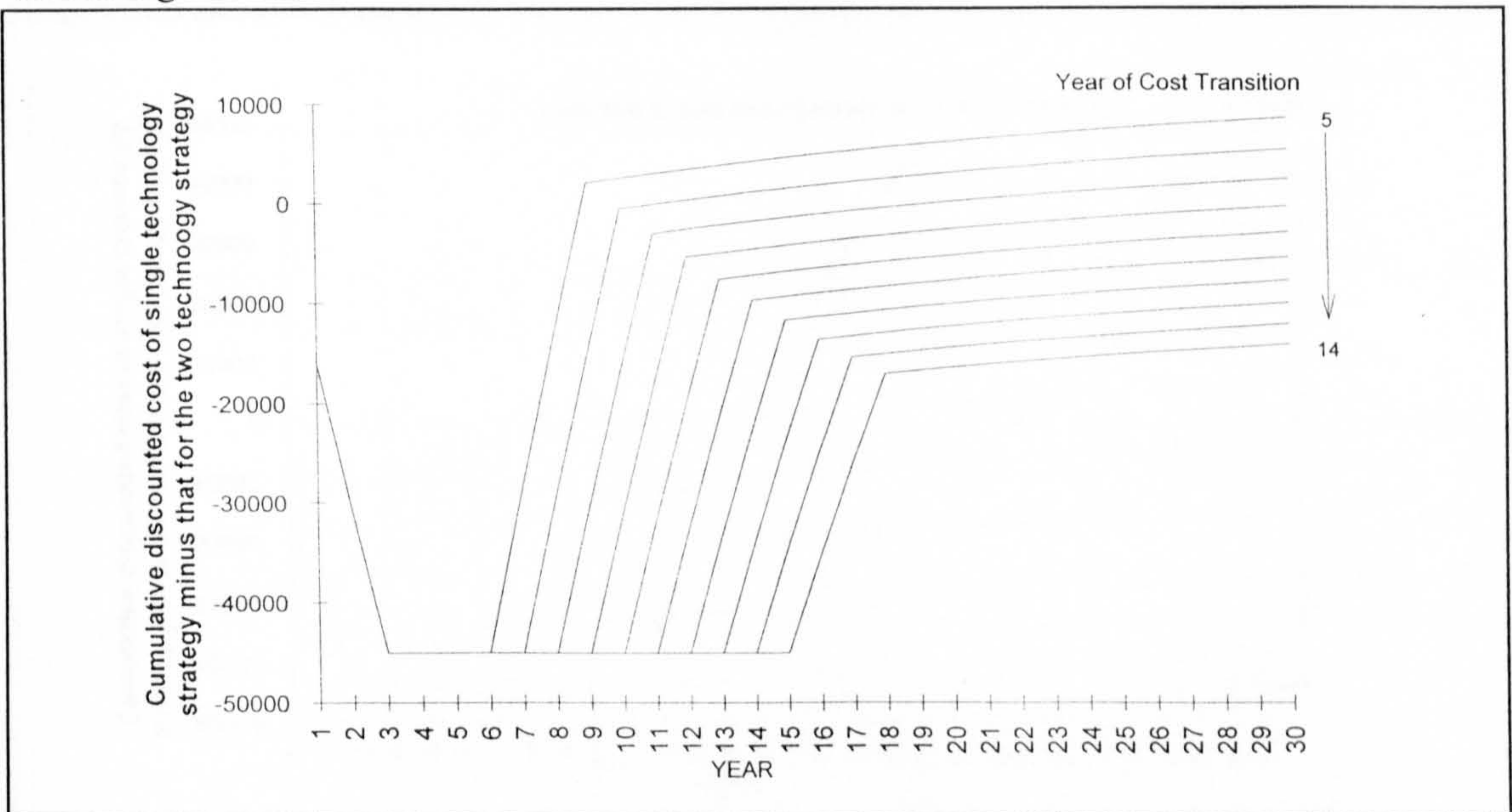


Figure 3.10 Influence of timing of 'price hike' on the utility of a diversified technological base.



Altering the rate at which the cost regime shift occurs has an analogous effect to changing the timing of the change (Figure 3.11). Finally, the time taken to construct additional units of plant influences the overall costs of operation. Figure 3.12 shows that longer lead times lead to higher costs for the Single Technology Strategy as it tries to react and build Technology #2 (replacement) at a time of high operating costs for its currently operative technology (Figure 3.12).

Figure 3.11 The influence of changes in the rate of 'price hike' on the utility of a diversified technological base.

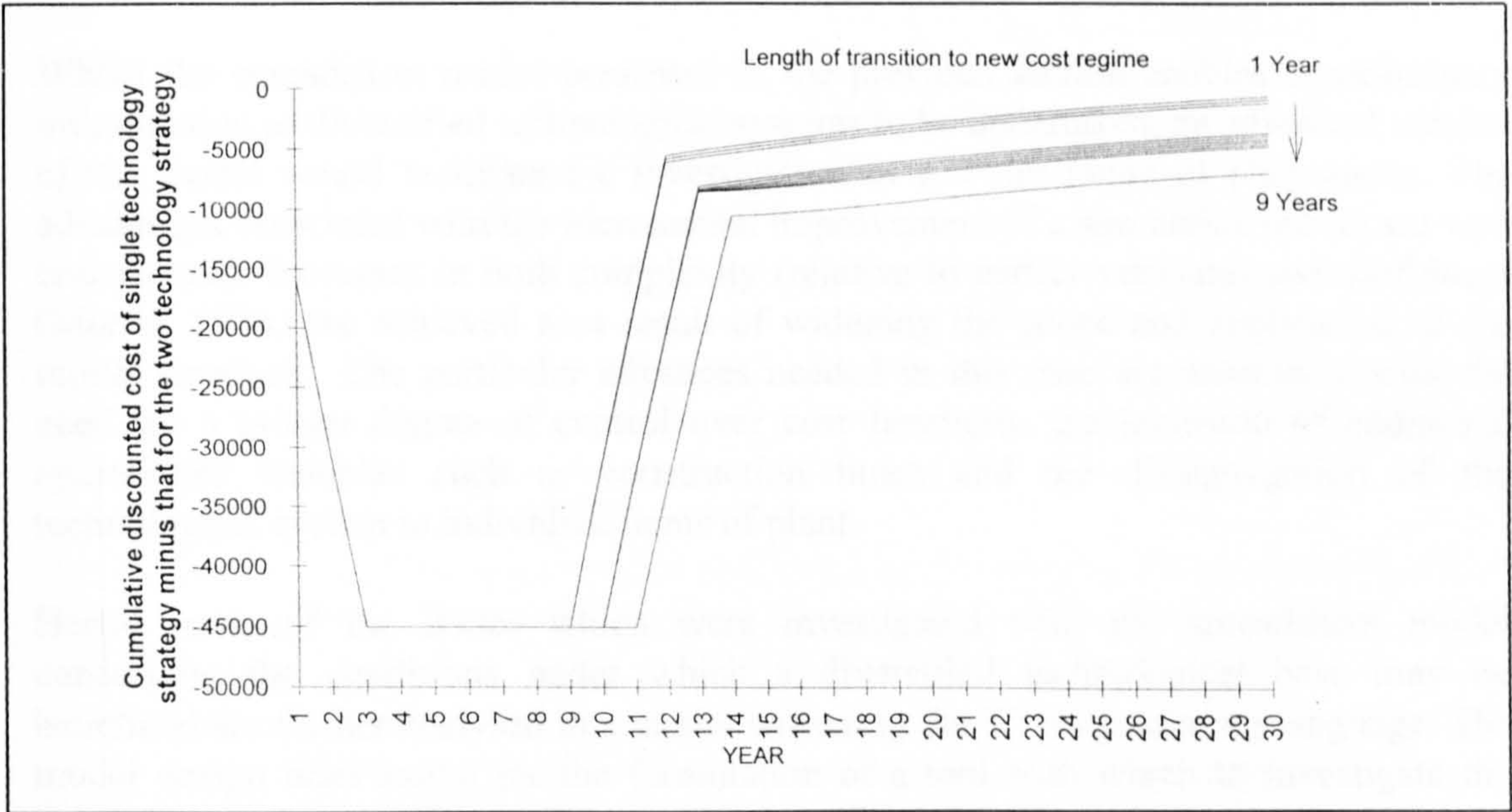
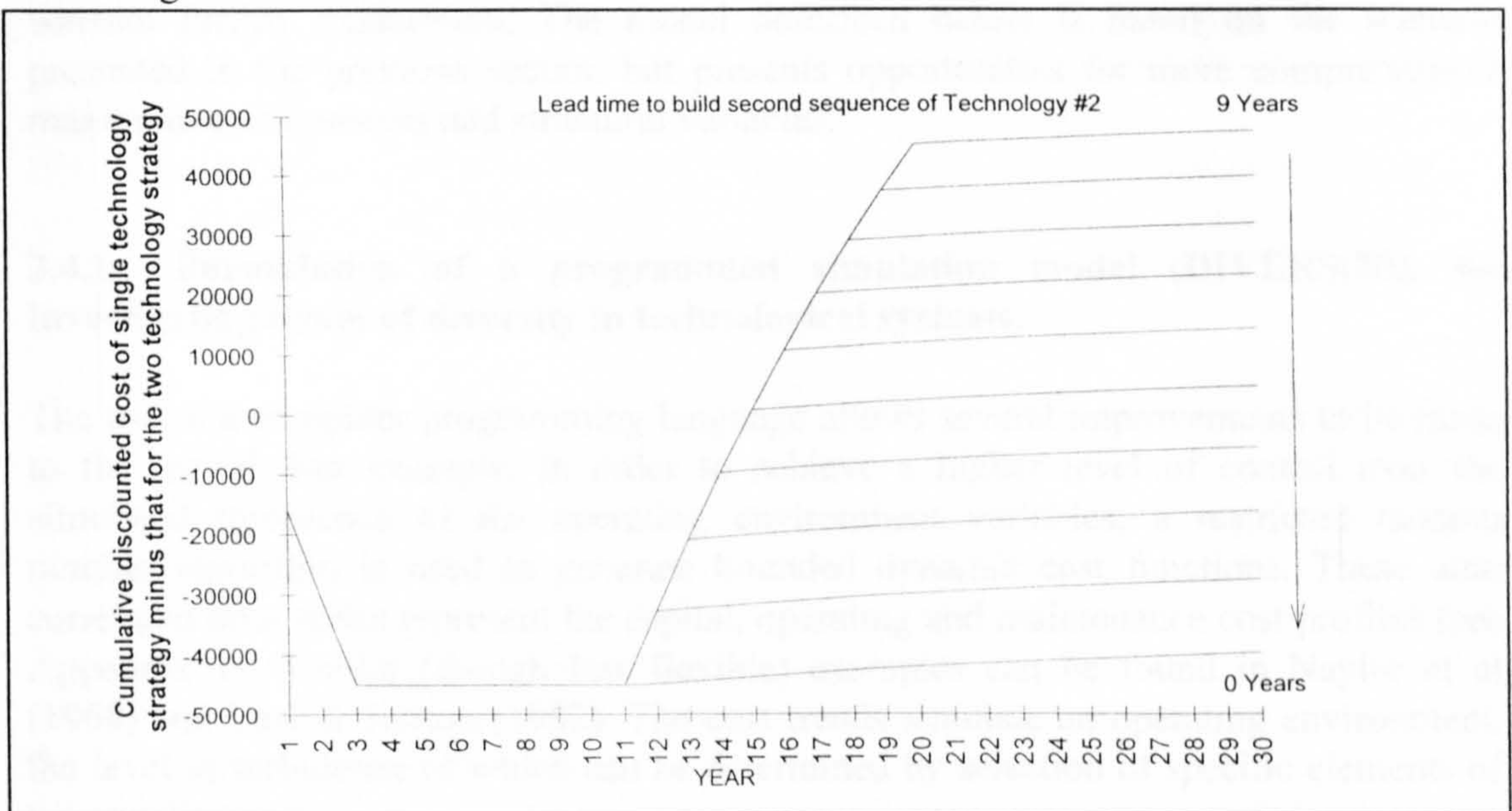


Figure 3.12 The influence of lead time to build on the utility of a diversified technological base.



In general the modelling activity presented above demonstrates the following:

1. The maintenance of a diversified technological base can be shown to be beneficial under certain conditions.
2. Overall utility with respect to the diversity represented in the model is highly sensitive to the timing of cost changes and relative movements of the cost

regimes associated with different technologies.

3.4 Development of an improved model.

Whilst the spreadsheet model presented in the previous section enables a preliminary investigation of diversified technological systems to be undertaken, an advanced version of the model would facilitate the investigation of a wider range of phenomena. The advantages associated with the incremental improvement of a simulation model are well documented. Increases in both complexity (relative to earlier versions) and usefulness (Morris, 1974) are achieved as a result of widening the scope and application of the model structure.. The particular advances needed in this case are associated with the need for a greater degree of control over cost functions, the inclusion of additional operational variables such as construction times and the disaggregation of the technological system to individual items of plant.

Hence some of the issues which were investigated with the spreadsheet model concerning the conditions under which a diversified technological base may be beneficial are further analysed in a model written in the 'C' programming language. The model design brief called for the formulation of a tool with which to investigate the influences of a range of cost elements on the utility of a diversified technological base over a single technology system. In particular, the issues of cost ratios and cost penalties associated with switching in and out of operating individual items of plant appear to warrant further exploration. The model described below is based on the scenario presented in the previous section but presents opportunities for more comprehensive manipulation of process and structural variables.

3.4.1 Formulation of a programmed simulation model (DIVERS(X)), for investigating issues of diversity in technological systems.

The use of a computer programming language allows several improvements to be made to the model. For example, in order to achieve a higher level of control over the simulated turbulence of the operating environment variables, a restricted random number algorithm is used to generate bounded dynamic cost functions. These auto correlated time series represent the capital, operating and maintenance cost profiles (see Appendix 1). Similar (though less flexible) examples can be found in Naylor et al (1968) and Law & Kelton (1982). The cost trends simulate an operating environment, the level of turbulence of which can be determined by selection of specific elements of the cost function.

Comparison of the two strategies (Single Technology and Two Technology), is achieved using two characteristics of the model. Firstly, a decision rule algorithm is employed to determine the two strategies adopted. Then, the total costs accruing to each strategy are recorded and compared to provide a relative measure of the success of each one. The total cost profiles are constructed on a modular basis and comprise the summation of capital, operating and maintenance costs together with the costs associated with

maintaining a plant ready for operation but dormant. In addition, penalty cost factors for switching between different types of plant are applied. As in the spreadsheet model, a two technology system is considered.

The costs accrued by each strategy are determined by a function which assesses the relative operating costs of each technology and allocates those costs to two strategies, one of which reflects a Single Technology Strategy, the other a Two Technology Strategy. The Two Technology Strategy involves the construction of 100% capacity of both technologies in year 1. This strategy is then liable for maintenance and dormancy costs for the excess capacity plus a penalty cost for switching between technologies. It does however have the option to operate the alternative technology when its associated operating costs are lower for any particular year. Diversity in this case is represented by redundant capacity; i.e. having plant constructed but not operational.

Assessing the conditions under which a strategy of diversifying the technological base of an organisation would prove beneficial is achieved by the use of the model (Divers(X)) outlined in Appendix 1. Only one investment event occurs in the base case, in year 1. After this point, the Two Technology Strategy operates the cheapest technology in each year and pays a cost penalty for switching between them. The Single Technology Strategy is only able to operate a single technology. Multiple runs of the model over 50 year time horizons are completed with the cost functions themselves being generated by the method described in Appendix 1. This allows some degree of control over each function but also generates a fluctuating trend which would not be possible with a simpler equation form. Utility is measured as the relative costs of the Two Technology Strategy to the Single Technology Strategy. Increases in this parameter therefore reflect an advantage from adopting the diversification strategy. In order to provide a relevant measure of technological configuration against which to assess utility, the cost ratio discussed in Section 3.3.3 is utilised as the x and y axes (the cost ratios for Technology #1 and Technology #2 respectively).

Given the model structure outlined above, there are circumstances under which the Two Technology Strategy will be able to benefit over the Single Technology Strategy, for instance where the operating cost function for Technology #2 remains below that for Technology #1 for extended periods. Conversely, the reverse effect would result in the diversification strategy being far more costly than the single technology investment. Potential savings from diversification would appear to be dependent upon the interaction between the ratios of the cost functions themselves and the costs which accrue to each firm. Additional elements of the system (reflected in the model configuration), will affect the relative utility of the diversification strategy. These include the timing of switches between technological options by the Two Technology Strategy, and the level of capital investment costs for each technology.

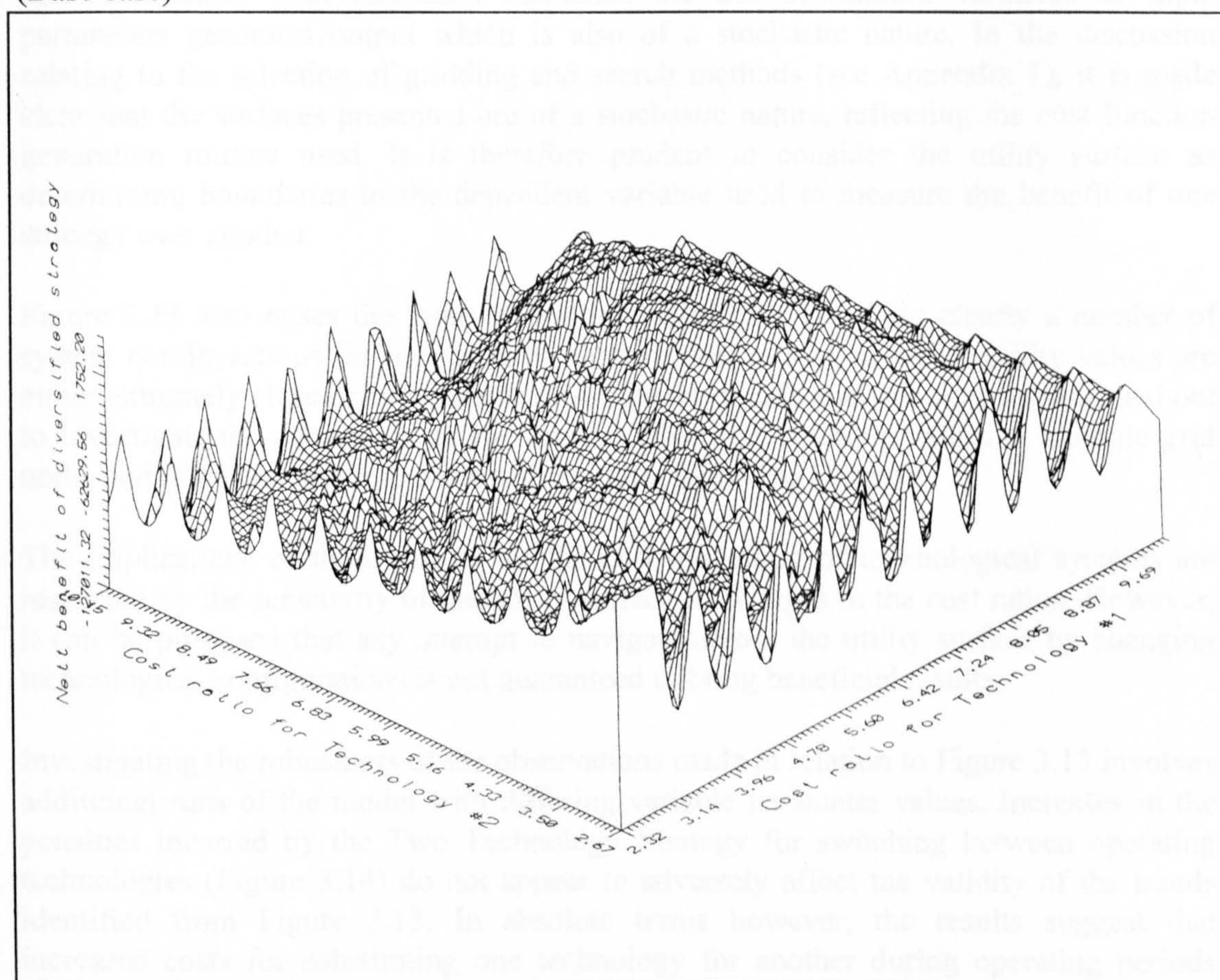
Analysing the model output leads to a number of conclusions regarding the influences of those parameters highlighted above. In particular, the selection of a set of measures with which to assess the utility associated with a diversified technological base emerges as a major methodological problem.

3.4.2 Results from DIVERS(x) Model

As a prologue to this section, the discussion presented in Appendix 1 concerning surface generation methods should be reviewed. The surface generated from the model data is representative of the difference in the cost of the Two Technology Strategy over the Single Technology Strategy. The term 'utility surface' is used throughout to denote the utility of the strategy of diversification over a strategy of single technology investment. Appendix 1 also provides a code listing for the model itself.

Results from the model suggest that the cost ratios (which were identified as an influential factor in the spreadsheet version) do not of themselves provide a reliable indication of potential benefit (Figure 3.13). This figure demonstrates that the utility surface is highly sensitive to changes in the capital / operating cost ratios of both technologies. In effect this phenomenon mirrors the turbulence of the cost functions used and illustrates how small variations in such functions can lead to radically different results. Therefore, movements over the utility surface to areas of greater cost benefit, (which may be achieved by organisations re-configuring their technology cost ratios), appears to be a highly risky strategy.

Figure 3.13 Output from model DIVERS(X) showing the utility of a diversified technological base as a function of changes in technology capital / operating cost ratios. (Base case)



There is a clear distinction evident in Figure 3.13 between the cost configurations which would result in higher and lower utility. In particular, a region of transition is identifiable on the utility surface which describes a shift from an area where low utility results are dominant, to a region where higher utility results dominate. This boundary is associated with movement along both the x and the y axes where the ratio of capital costs to average operating costs is rising. In turn this is representative of situations where the Two Technology Strategy is confronted with an increased potential for recovering the additional costs of building two technologies (i.e. the advantages of having two technologies are increased). There is also a relative distinction in benefits to be drawn between the influence of each technology's cost ratio, shown by the region of instability which bisects the area of higher utility. This data set thereby suggests that the adoption of a technological configuration with diversified cost elements can be beneficial over longer time horizons.

The results presented in Figure 3.13 represent a scenario based on a single cost function trend, i.e. the cost function parameters, whilst including stochastic elements, were maintained fundamentally unchanged during each run. In the context of the model's application therefore, some reference to the input variables is required in order to provide a setting for the results. The model cannot generate any trend or characteristics which are not a reflection of either its internal structure or the input values used. In the case of models with stochastic elements, the use of random variables as input parameters generates output which is also of a stochastic nature. In the discussion relating to the selection of gridding and search methods (see Appendix 1), it is made clear that the surfaces presented are of a stochastic nature, reflecting the cost function generation routine used. It is therefore prudent to consider the utility surface as determining boundaries to the dependent variable used to measure the benefit of one strategy over another.

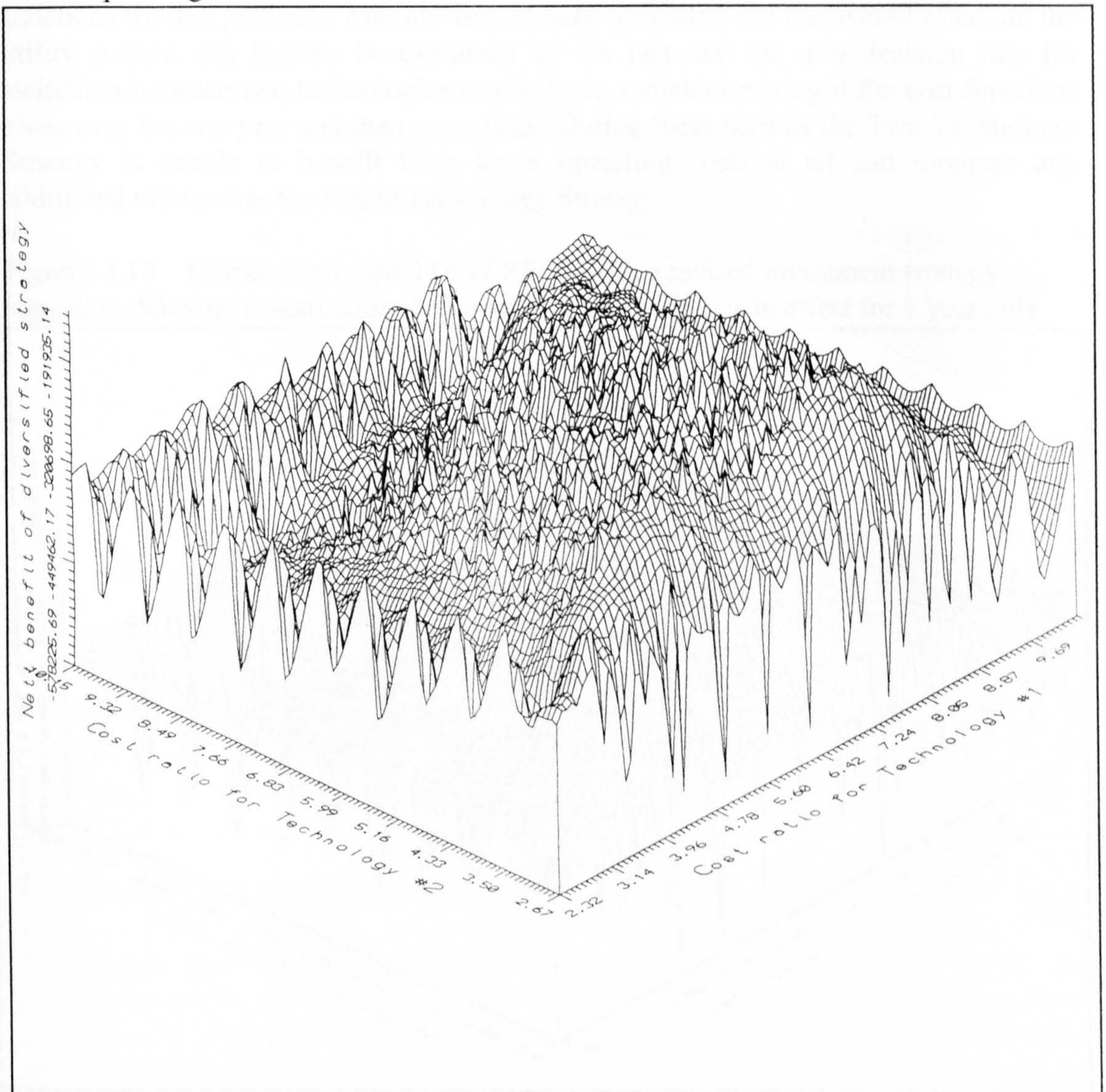
Figure 3.13 also raises the issue of multiple solutions. There are clearly a number of system configurations (as measured by the two cost ratios), at which utility values are either extremely close or even identical. A number of data analysis tests were carried out to investigate the occurrence of the inverse effect, i.e. multiple values at a single grid node, and this phenomena is dealt with at in the following Chapter.

The implications of these results for the cost modelling of technological systems are restricted by the sensitivity of the utility surface to changes in the cost ratios. However, it can be proposed that any attempt to navigate across the utility surface by changing technological configurations is not guaranteed to bring beneficial results.

Investigating the robustness of the observations made in relation to Figure 3.13 involves additional runs of the model with differing variable parameter values. Increases in the penalties incurred by the Two Technology Strategy for switching between operating technologies (Figure 3.14) do not appear to adversely affect the validity of the trends identified from Figure 3.13. In absolute terms however, the results suggest that increased costs for substituting one technology for another during operating periods

leads to lower overall utility from a strategy of diversification. An obvious contributing factor to the magnitude of this element of the analysis is the number of substitution events which occur. In this context, the benefits from switching become a function of the trade off between the costs of the second (alternative) technology, the costs of switching, the number of switches, and the magnitude of saving which accrue from each switch. Whilst the first and second of these parameters can be assessed at the time of switching, the latter two are indeterminate as they rely upon the future performance of the technology and trends in the relevant cost functions. A second feature of Figure 3.14 is that as a result of the substitution being more costly, the region which was identified as representing a boundary between the relative contribution of each technology's ratio to increased utility (the 'face' running from high x,y points to low x,y points) is less well defined.

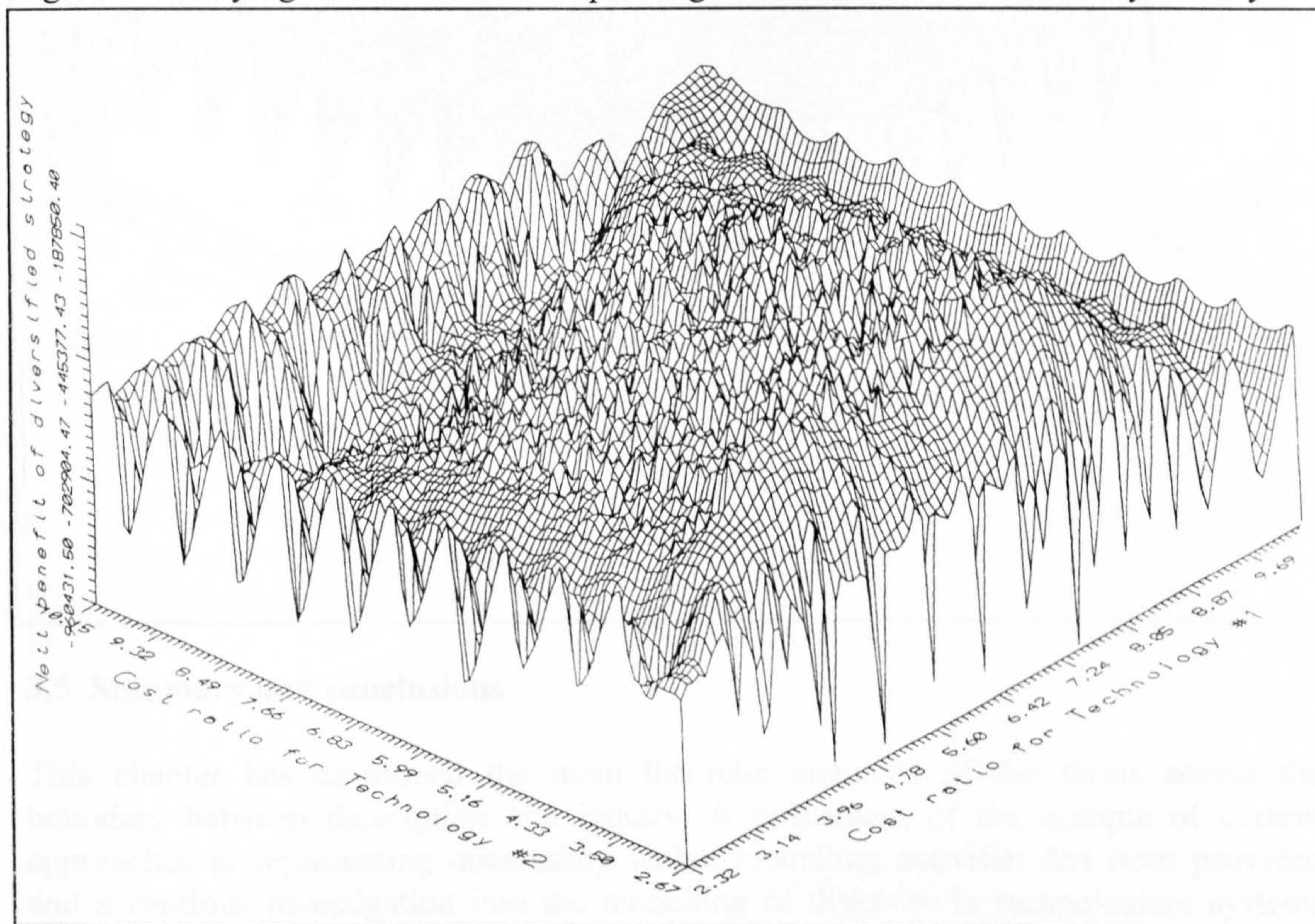
Figure 3.14. Output from model DIVERS(X). Parameters as for base case but with increase in penalty factor for switching between technology types in order to access to lower operating costs.



The frequency with which the Two Technology Strategy switches between operating each plant type will have an obvious influence on the utility of a diversified technology base. A situation where operations cost functions are closely correlated and exhibit highly fluctuating relative values will encourage a large number of switching events. This will in turn lead to higher overall costs due to the cost of switching being accrued frequently. One possible strategy with which the excesses of this phenomenon can be combated would be to delay the switch-over event by 1 year. This would have the effect of limiting the number of possible switching events to $n/2$ instead of the n possible if the switch is allowed to occur in any year.

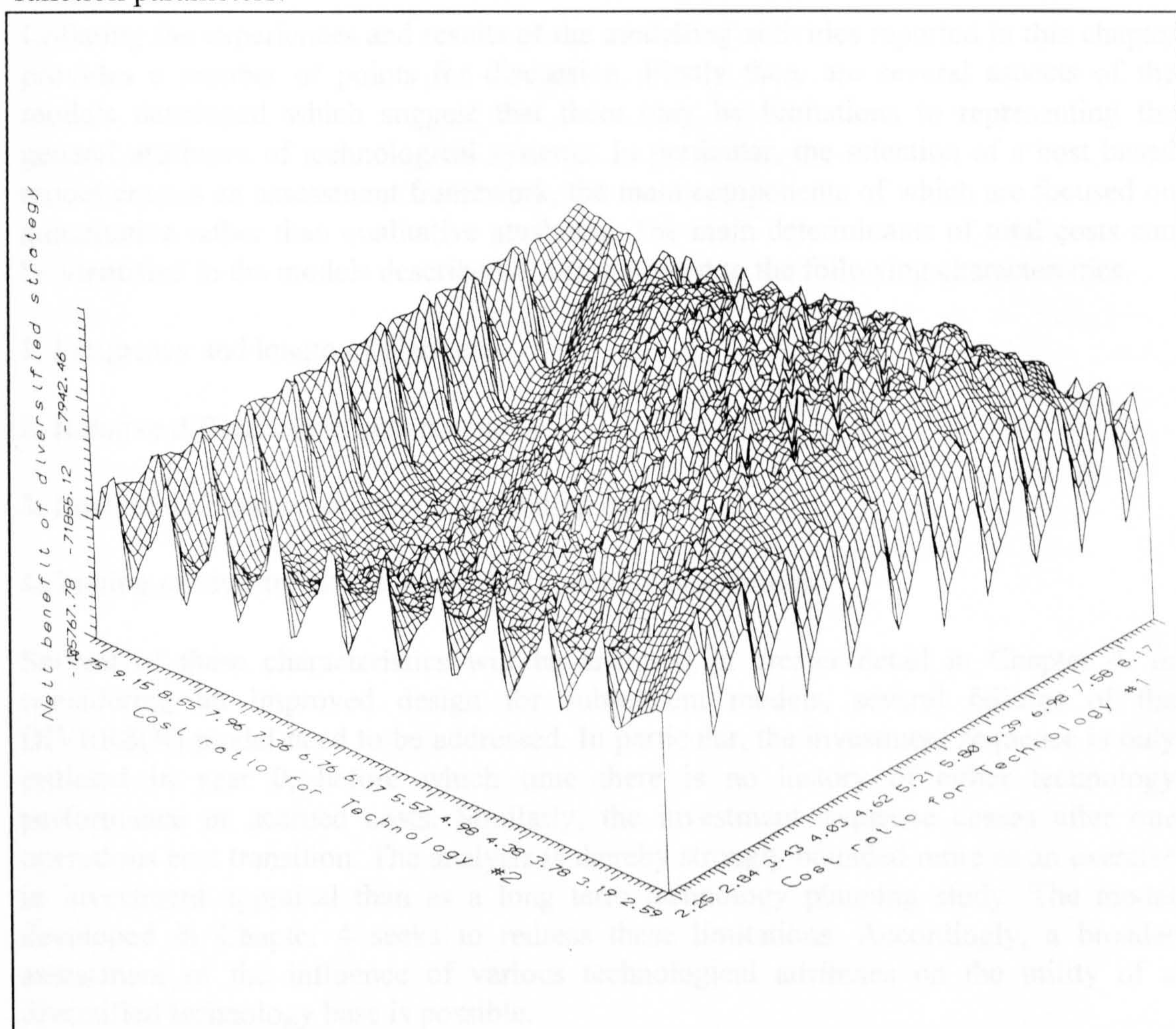
However, simulating such a revised technology switch decision rule results in both an overall decrease in the utility associated with the strategy of technological cost diversification, and an increased range of values for the utility measure (Figure 3.15). The major trends on the utility surface associated with the changes in cost ratios still hold under these circumstances. However, the distinctive feature which bounds movements in each technology cost ratio disappears altogether. The operations cost functions for this particular case are very closely correlated and the overall effect on the utility surface can thereby be explained by the fact that the new decision rule for switching between two technologies results in no switch occurring if the cost functions cross over for one year and then cross back. During these periods the Two Technology Strategy is unable to benefit from lower operating costs at all and foregoes any additional utility over the Single Technology Strategy.

Figures 3.15 Output from model DIVERS(X) with a revised investment strategy algorithm delaying construction if an operating cost switch is in effect for 1 year only



These results highlight the influence of the trade offs identified in Section 3.4.3 but supply little succour for decision makers with regard to specific technology configurations. Additional runs of the model supported this point by illustrating the wide range of possible outcomes and the sensitivity of results to relatively small changes in the cost function variables. An example of this is provided by reference to Figure 3.16 which depicts the results from the simulation with similar parameter settings to Figure 3.13. The difference between the two surfaces result from limited alterations to some of the cost function parameters ($\pm 5\%$). Whilst the general trends are again maintained, the surface exhibits different regional prominences and features.

Figure 3.16 Output from DIVERS(X) model. As base case but with slightly varied cost function parameters.



3.5 Summary and conclusions

This chapter has developed the main theoretic elements of the thesis across the boundary between description and inquiry. A refinement of the critique of current approaches to representing uncertainty within modelling activities has been provided and a cautious investigation into the modelling of diversity in technological systems

undertaken. The results of this investigation suggest that there is potential benefit to be attained from taking the modelling activity further and in developing a more complex model to enable other aspects of the problem to be assessed. A continuation of the modelling activity is therefore pursued in the following chapter.

In general, the results demonstrate some of the problems which accrue from the use of a stochastically based model. More particularly, it is clear that care must be taken in deriving any firm conclusions from data sets which exhibit such unstable trends. Of greater import is an appreciation of the links between model input variable settings and structure, and interpretation of the output. Using this framework as a basis for an analysis of the model presented, it has been shown that diversity of technology types can be a beneficial strategy over a range of conditions.

Collating the experiences and results of the modelling activities reported in this chapter provides a number of points for discussion. Firstly there are several aspects of the models developed which suggest that there may be limitations to representing the general attributes of technological systems. In particular, the selection of a cost based model creates an assessment framework, the main components of which are focused on quantitative rather than qualitative attributes. The main determinants of total costs can be identified in the models described as being related to the following characteristics.

1. Frequency and length of plant use.
2. Relative differences in cost functions.
3. Interaction between capital and operating costs.
4. Timing of investment and technology operations activities.

Several of these characteristics will be analysed in greater detail in Chapter 4. In considering an improved design for subsequent models, several failings of the DIVERS(X) model need to be addressed. In particular, the investment sequence is only initiated in year 0, before which time there is no history of either technology performance or accrued costs. Similarly, the investment sequence ceases after one operations cost transition. The analysis is thereby strongly bounded more as an exercise in investment appraisal than as a long term technology planning study. The model developed in Chapter 4 seeks to redress these limitations. Accordingly, a broader assessment of the influence of various technological attributes on the utility of a diversified technology base is possible.

CHAPTER 4

MODELLING RESILIENCE IN TECHNOLOGICAL SYSTEMS: DEVELOPMENT OF AN ADVANCED MODEL AND THE EMERGENCE OF SOME METHODOLOGICAL PROBLEMS

4.1 Introduction

Chapter 3 reported the development of a simple total cost model for assessing the relative utility of a diversified technological base over a single technology system. The expansion of this modelling activity forms the subject matter for Chapter 4. A considerably more intricate simulation model is assembled, providing both greater functional flexibility and wider opportunities for exploring the technological characteristics of resilience discussed in Chapter 3. Whilst the general format of the model is similar to that in the 'DIVERS(X)' model, its modular structure enables a much higher degree of control over an extended set of parameters.

Prominent characteristics of the model (titled 'LTIME'), include the capacity for specific technological configurations to be determined. This allows variations in technology type, lead-time to build, performance characteristics, maintenance schedules etc. to be analysed. Additionally, a set of functions are included which determine the relationships between costs, plant size, plant age, and various efficiency parameters. A plant operation algorithm (similar to that used in the DIVERS(X) model) is utilised to determine plant scheduling sequences and reinvestment programmes. The output from the model is discussed and, following an appreciation of some specific limitations to the model's use, a number of possible applications are explored.

The model presented is complex in the sense that there are multiple causal influences on the measured output values, in addition to the inclusion of a number of decision rules which serve to create non linearity in the recorded trends. Despite this, the model is not complicated as the general principles which determine the model structure and the principles which dictate the emerging variable relationships are easily explained.

Much of the details concerning the structure of the LTIME model can be found in Appendix 1 which also provides supporting material relating to the operation of the cost functions used in both this and the DIVERS(X) model.

4.2 Development of a second programmed simulation model (LTIME), to investigate issues of diversity in technological systems.

Further investigations into the influence of a diversified technological base on long term total costs is undertaken with a second computer model designed to expand the form and scope of the analysis. Appendix 1 provides a detailed code listing of the model and its

supporting structures. This second 'C' model is designed on a modular basis. The cost generation, investment, and operation decision rule elements of the algorithm being maintained as separate entities to facilitate ease of manipulation and development. Being of a more complex form (in relation to number of variables and structure), the development time involved was relatively long compared with the previous model. Despite this, the resultant code is not impenetrable and it possesses, in the form presented in Appendix 1 the potential for further expansion and refinement.

In general, the aim of this modelling exercise is to devise a tool with which to investigate some of the questions emanating from the theoretical work which were not amenable to investigation via the previously described models. A richer, more specific analysis is required in order to provide greater support and validation for the results generated by earlier models. As a preface to a discussion of the model's output, a brief illustration of its major constituent elements is presented below.

The LTIME model initially adopts the two technology outline of the previous model although provision is made for the addition of further technology types. Five sub-programs are utilised, each one being called as a sub-routine from the main function. These sub-programs constitute decision rules for each strategy regarding building and operating of plant and a cost function generation routine which provides capital, operating and dormancy costs as well as handling the evaluation of a demand function. Ongoing records of each strategy's technology base and each technology's cost characteristics are maintained. These are then utilised to determine operating technology selection and investment criteria. A number of input data files are also provided to enable variability in design life, technology scale and other parameters to be applied to the basic cost components. The model is initialised by setting up a current technology base for each strategy and ascribing a range of design and cost parameters to each unit of plant, including age, lead time to build, current status and capacity. Cost functions for each technology type are generated in a similar fashion to those for the DIVERS(X) program and a demand function is also calculated.

The actions of each of the two strategies (two technology and single technology) are then simulated at yearly intervals with plant investment and operating decisions reflecting current costs and technological characteristics. It should be noted that the labels 'single technology' and 'two technology' do not refer to the number of items of plant but to technology types. Each strategy is able to access multiple units of plant of each technology type. The technology types themselves are analogous to technologies using different input factors to generate a single product or service.

Plant operation is managed by an operations sub-routine which sorts the set of available technologies into an operating order, dictated by age and operating cost criteria. Consecutive units of plant are then brought on stream until demand is satisfied. All other built units attract a penalty cost for being maintained available but dormant. A survey of each plant set is then carried out to ascertain the need for replacement plant or new capacity to meet demand. Finally, yearly and cumulative costs accrued by each strategy are calculated together with the capital / operating cost ratios which are used to

represent the configuration of the whole system in the graphical output.

As the cost simulation algorithms contain a stochastic element, multiple runs of the model need to be completed for a reliable data series to be generated. Unlike the cost generation algorithm used in the DIVERS(X) model, this algorithm exerted a heavy demand on computer time and required the use of an advanced specification P.C. for both source code compilation and running. Data generation was achieved by the use of iterative loops and resetting of variables to enable the effects of a range of cost ratios to be analysed during a single run of the model. Execution time varied from approximately 3 hours on a network based system using a 486 33MHz machine, to 12 hours on a 386 25MHz stand alone P.C. Appendix 1 contains details of the input parameters used in the base case.

The model's intended application is to enable issues of technology cost diversification and flexibility to be investigated within a structure which allows the representation of realistic investment strategies and dynamic cost functions. Within these criteria, the program fulfils expectations although at some cost in complexity and analysis time. The large number of parameters available for permutation and modification enables a wide range of scenarios to be addressed. Included in this are the cost and demand functions which, whilst possessing stochastic elements allow underlying trends and regime switches to be dictated. Some practice and experiment is required to gain a demonstrable level of control over these functions but, once achieved, it allows the functions to be manipulated in a variety of ways. The following list of model variables are of particular relevance to the study in hand.

Initial technological configuration: The model is initialised with a 'current' technology set for each strategy which can be varied in number, size and age to reflect a particular technological system configuration at year 0. The model thereby begins each simulation with an operating plant set that already possesses a history of operation.

Cost functions: As discussed above, these are determinable within certain bounds. The level of control available provides enough scope for 'price hikes', dynamic environments and other types of cost profiles to be dictated (e.g. linear, cyclic, step function etc.).

Demand Function: This is generated within the same algorithm as the cost functions and allows the demand levels faced by each firm to be dictated.

Technological attributes: Scale, design life, and other technological characteristics of each individual item of plant can be set, providing the potential for investigations of technology configurations and design parameter issues.

Decision rules: The criteria which govern plant operation and determination of investment in new or replacement plant can be influenced and, if need be, altered by the inclusion of a separate algorithm. This allows a variety of investment and operating strategies to be assessed under differing operating environments.

Out of the several tasks which the model is capable of fulfilling, the one selected for initial utilisation involved an investigation of the benefits of an investment strategy focused on diversity of technological attributes (represented by the possession of more than one technology type).

4.3 Discussion of model output

As an initial step to corroborate and confirm the model's relative accuracy with the earlier version, a run of the model was executed using variable parameters of a similar range to those found in the DIVERS(X) model. Figure 4.1a illustrates the data output from this run. The utility surface conforms to the trends identified in the previous Chapter. N.B. Each utility surface is calculated in a similar way to that of the DIVERS(X) model (i.e. costs of Single Technology Strategy minus the costs of the Two Technology Strategy).

Although the surface generation method and stochastic function generation algorithms used in each model are identical, there are several key features of Figure 4.1a which are different from the figures presented in Section 3.3.3. These differences are reflective of the variations in model structure and the range of technology cost ratios represented on the x and z axes. Nevertheless, the broad trends of decreasing utility value of the strategy focused on diversity with increasing Technology #2 cost ratio, and increasing utility value of the strategy focused on diversity with increasing Technology #1 cost ratio, are maintained. Furthermore, the relative rates of change across these vectors remain constant with changes along the Technology #2 axis resulting in higher rates of change than movements along the Technology #1 axis.

Figure 4.1a Output from LTIME model. Base case used to configure it with the DIVERS(X) model.

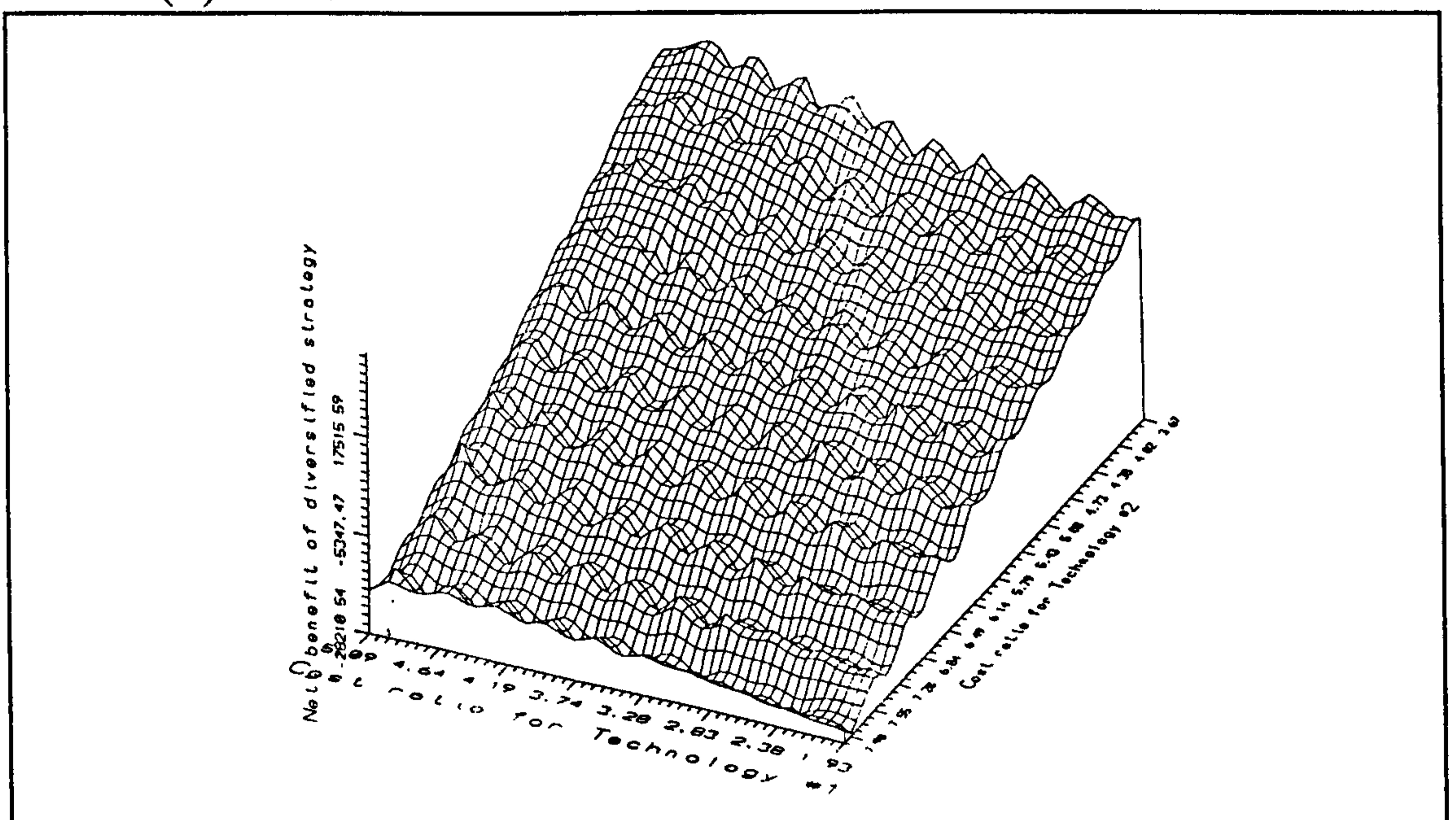
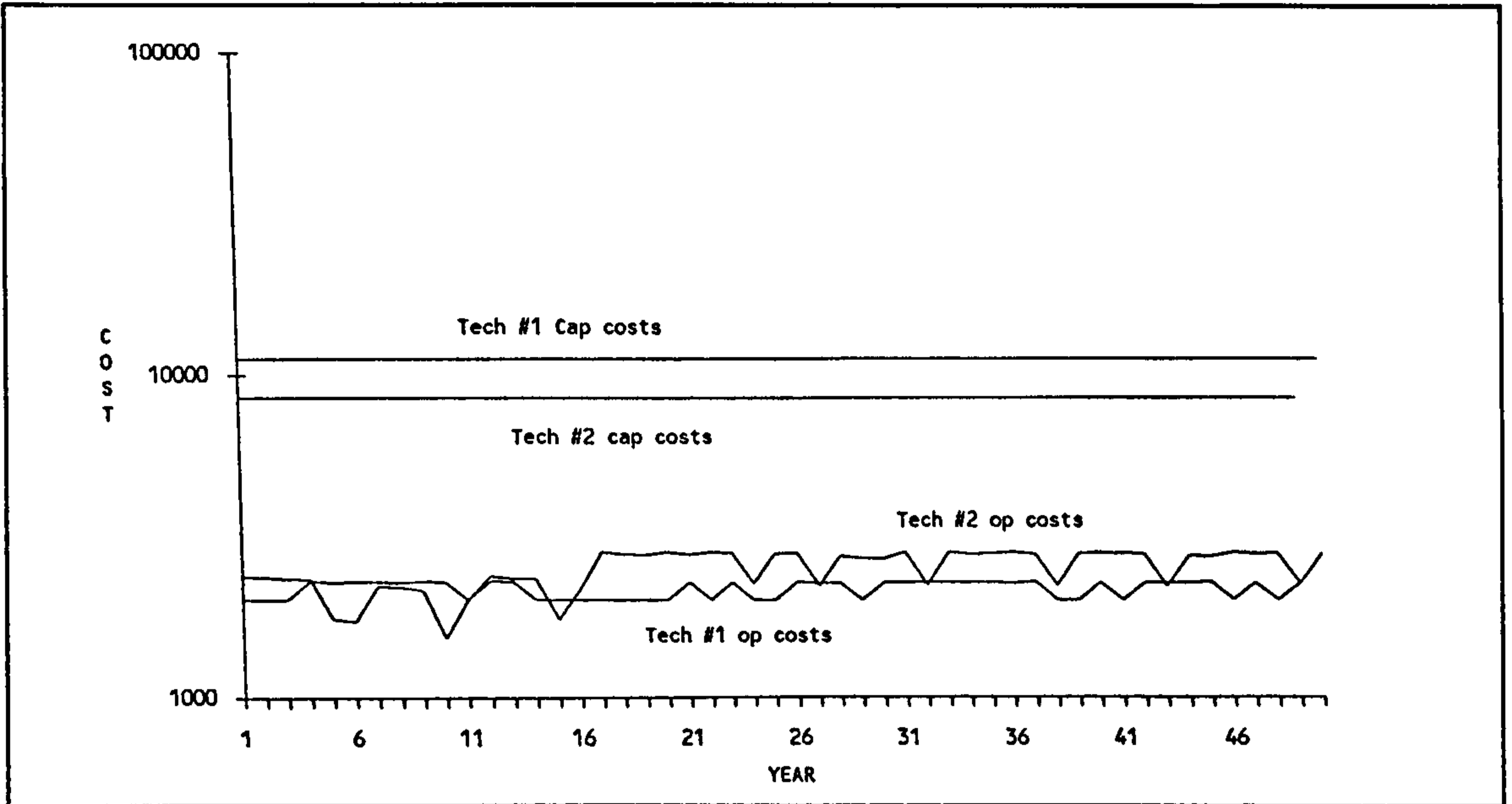


Figure 4.1b Representative cost functions used during generation of Figure 4.1a.



Further confirmation of the model's analogy with the earlier version can be gleaned from Figure 4.2a. The parameter settings for this run of the model have been changed to create an operating environment characterised by closely correlated operating costs and altered magnitudes of influence for scale and age effects. These changes promote large capital cost savings for small scale units and reduce the cost penalty of increasing plant age to reflect more effective maintenance procedures (both achieved by alterations to the relevant data input files).

Figure 4.2a Output from LTIME model. Parameters as with base case but with closer operating cost trends (see Fig 4.2b below) and changed scale and age effects on plant efficiency.

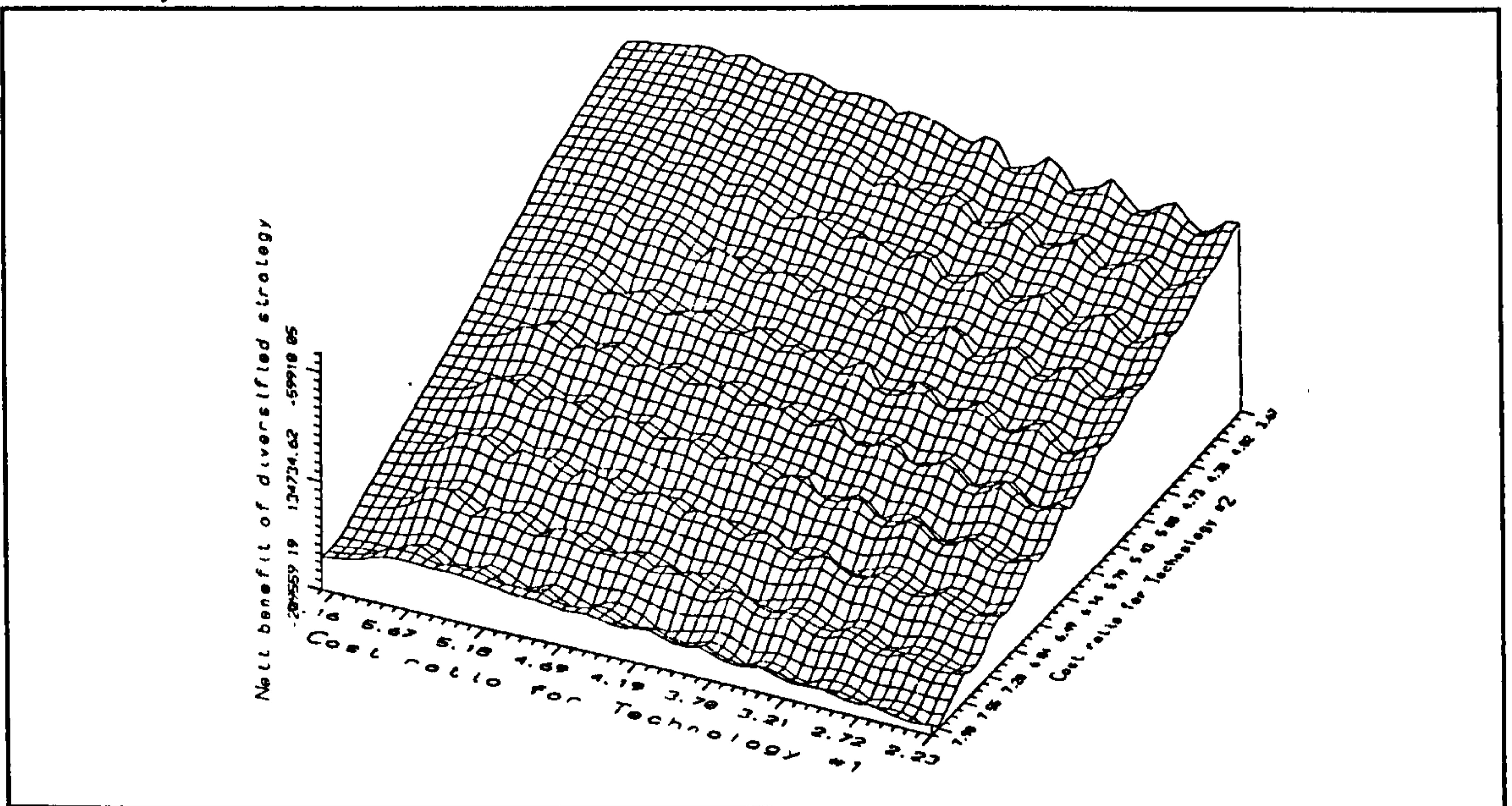
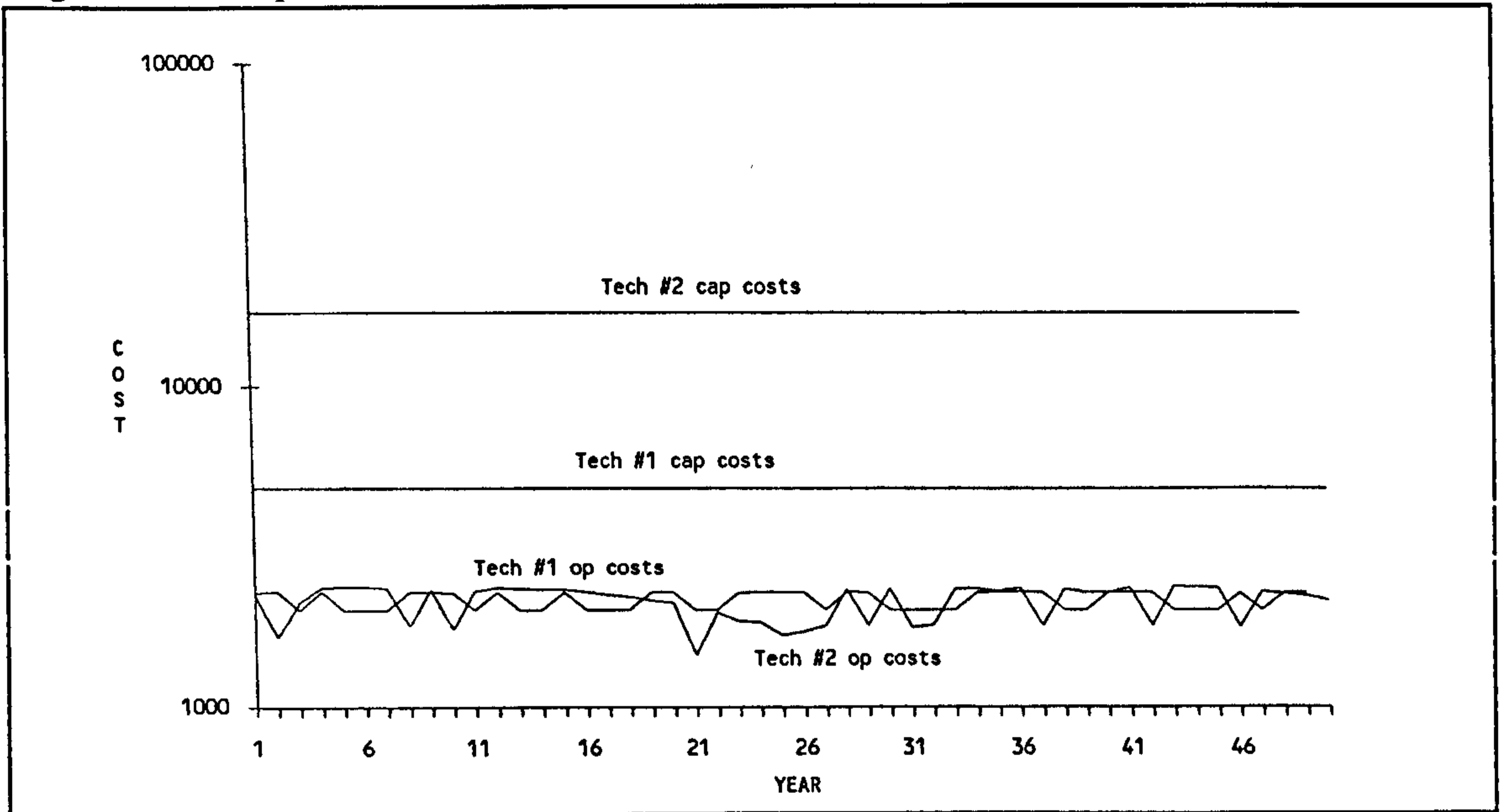


Figure 4.2b Representative cost functions used during generation of Figure 4.2a.



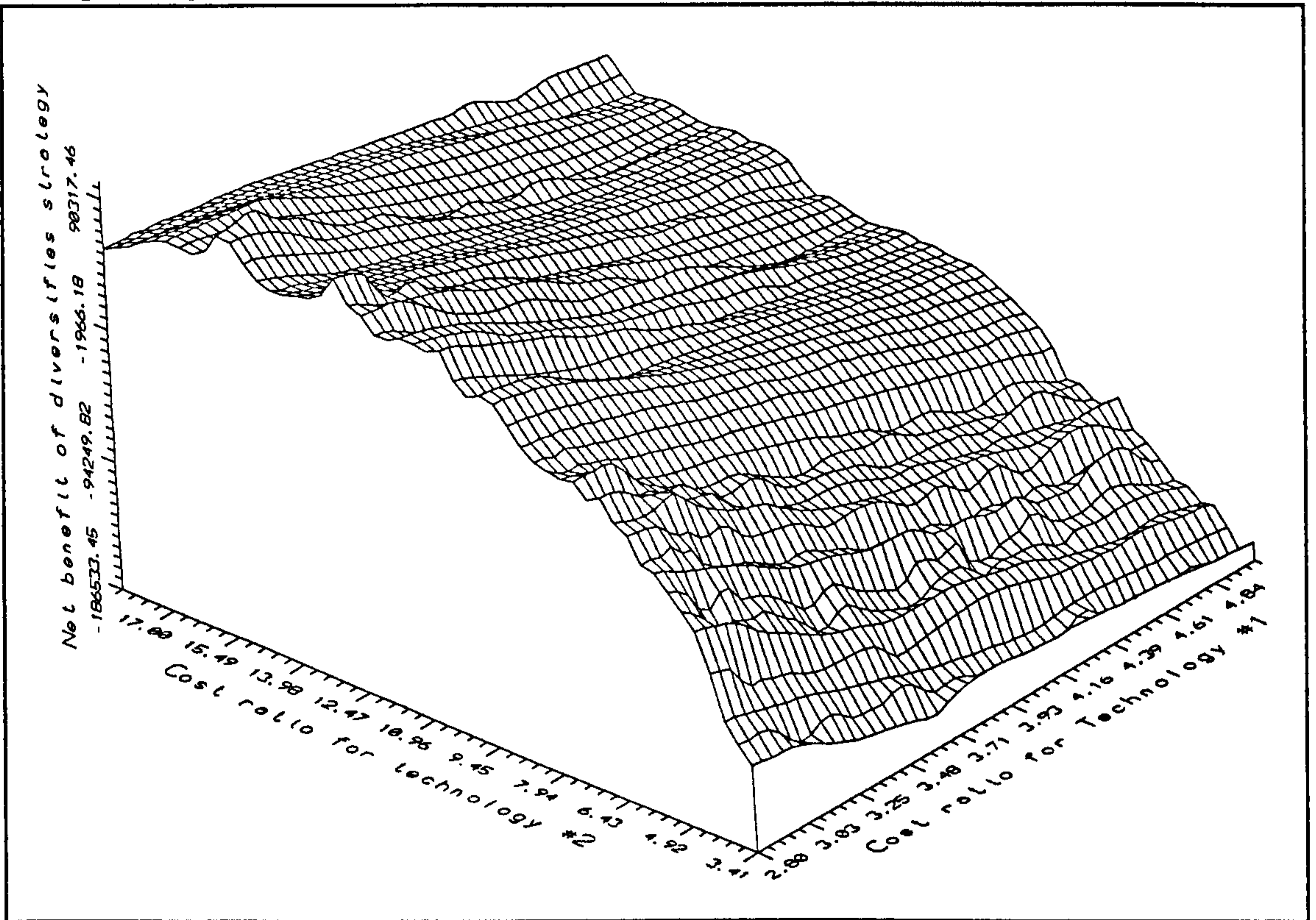
The resulting output exhibits identical overall trends to Figure 4.1a. However, the absolute values represented by the utility surface are far below those for the previous simulation run. The explanation for this lies in the close correlation between the two operating cost functions. As was shown in the previous section, such a situation leads to the Two Technology Strategy being heavily over-invested and it is unable to operate the alternative technology for long enough periods to allow any benefits to be gained over the Single Technology Strategy. The changes in incurred costs due to the age of the plant and unit scale effects were of little influence relative to that of the overall operating cost trends. The importance of identifying the relationships between the various cost and technology configuration elements was raised in the previous section. The results shown in these two figures serve to emphasise this point.

Subsequent to confirming the behaviour of the initial simulation runs against the previous model's output, a set of simulations have been executed with the aim of examining the influence of changes in those characteristics represented in the model on the overall utility of maintaining a diversity of technology types. During this phase of the modelling activity several issues emerged as limiting factors to output interpretation and analysis.

A case in point is shown in Figure 4.3. This utility surface depicts the results of a simulation run which closely followed the parameters used for Figure 4.2a, the major differences being that the operating cost functions were changed relative to the capital cost functions to enable the relevant cost ratios to be generated. (In Figure 4.2a, the capital cost functions were fluctuated relative to the operating costs). The regime switch was also transferred from the operating cost element to the capital cost element of the total cost profile. The major feature of Figure 4.3 is the reversal in the trends identified in Figures 4.1a and 4.2a (i.e. increases in the Technology #2 axis ratio result in increased advantage of the diversification strategy and decreases in the Technology #2

axis ratio have an opposite effect.) These results are contradictory, even though the capital and operating cost profiles encountered by each strategy remain essentially similar.

Figure 4.3 Output from LTIME model. Cost ratios achieved through changing operating costs relative to capital costs rather than moving the capital costs in relation to the operating costs.



The explanation for this trend inversion can be traced to the relative movements of the cost functions not only on an intra-technology basis but also on an inter-technology one. Changes generated in the cost ratio of Technology #2 by movements in the capital cost result in the higher values on the relevant axis reflecting Technology #2 becoming progressively as expensive and then more expensive than Technology #1 to build. As long as the operating costs of the two technologies are closely correlated this will result in the Two Technology Strategy becoming more heavily burdened with the costs of providing an alternative. It is thereby less able to recoup these investments via operating cost savings when conditions allow. Moving the operating cost functions relative to the capital cost trends however, results in high ratios being associated with a situation where the operating costs for Technology #2 are significantly lower than those for Technology #1. Hence, the Two Technology Strategy is able to operate the cheaper technology continuously, thereby accruing large relative benefits over the Single Technology Strategy. From these results it can be seen that the relative movements of cost functions not only along the time series, but also with regard to their comparative magnitudes, are an important influence on output data sets.

The main conclusion from this particular run of the model must therefore be that the parameter selected to measure technological attributes (i.e. capital / operating cost ratio), is not a robust indicator of the influence of technology configuration on utility. Following this analysis, several alternative cost based parameters were isolated and used as replacements for the capital / operating cost ratio. However, these proved to be just as ineffective. An effort was also made to identify an alternative type of term for the parameter, including the use of vectors and matrices. Again, the resulting variables were not able to deliver unambiguous information about technological cost configurations and were rejected.

The root of this problem lies in isolating a measurement parameter which allows complex information to be presented but which exhibits a unique value for each possible information point. Combining factors such as capital and operating costs into a single parameter allows a relatively complex measure of cost behaviour to be presented. However, the associated problems of non-unique parameter values makes data interpretation problematic. This issue of measurement parameter identification was of enough significance to bring this stage of the modelling activity to a halt. Alternative uses of the model output are reviewed in Sections 4.5 and 4.6, following a review of the phenomenon of multiple solutions which arose in both the DIVERS(X) and LTIME model output.

4.4 Multiple solutions and concepts of equifinality.

As mentioned in the previous chapter, the occurrence of multiple values at a single grid node was investigated for both the DIVERS(X) and LTIME model. For the model runs which generated Figures 4.1-4.3, more than one value was obtained for approximately 15% of grid nodes. This phenomenon suggests that there are multiple pathways across which equifinal states can be achieved. A 'pathway' in this context is characterised as a consecutive set of states exhibited by a system over time. These may be quantitative or qualitative in nature and describe structures, values, status, or configuration. Multiple solutions, as a problem associated with stochastic and dynamic based models, is not a new phenomenon and nor should it be an unwelcome one. The issue of pathways, to be discussed in more detail in Chapter 8, provides an additional example of the desirability of determining the possible advantages to be gained from the existence of equifinal sequences of actions. If the mechanisms which generate such multiple solutions are investigated, there are a further series of apparent paradoxes which call for analysis. In particular, relative changes in the contributing elements of an overall output measure may result in contradictory trends. Again, this is not a surprising occurrence given the complexity of the data generation procedures. Interpretation of output must however be comprehensive enough to enable these and other inconsistencies to be exposed.

The combinatorials which form a framework for pathway analysis at this simple modelling level can be addressed using conventional mathematical relationships. The relevant terms and expressions are presented below.

For any variable with 'S' possible discrete states and 'T' time intervals over which any state can occur, the number of possible different sequences (allowing for repetition of states) can be expressed as:

$$S^{(T+1)}$$

Summation of these sequences provides final state values for the variable under consideration. The number of final states is identified by the term:

$$(T+1)(S-1)+1$$

It is also possible to identify the minimum, maximum and mean values of these summations if the allowable states are regularly spaced with interval 'K' and the minimum state 'X' is known. Thus:

$$\text{Minimum value} = (T + 1) X$$

$$\text{Maximum value} = (X + (S-1) K) (T+1)$$

Although the mean value can be easily calculated from this, the derived figure may not be one of the discrete values allowed.

For the case where more than one variable is under analysis, the total number of discrete summed end states (assuming that no combinations of discrete end states is similar) is given by:

$$S_1 \cdot S_2$$

where S_1 is the number of unique end state values for Variable #1 and S_2 is that for Variable #2.

The values obtained will form a normal distribution about the mean, thereby providing an indication of dominant permutations or the most likely final state given an equal probability for each pathway. This analysis would simply remain a basic exposition of probability theory without the concept of pathways.

The unique feature regarding an interpretation of multiple solutions which adopts an equifinal pathway analogy rather than simply a resultant probability distribution, concerns the issue of process planning. Using a probability distribution to interpret the model results fails to provide information regarding the experiences and history of the resulting system configuration. Conversely, an analysis of the pathways which determine a final system state allows an assessment of process and dynamics which influenced the final or intermediate discrete situation. This is particularly important where opportunities for change are available. At such 'change nodes' where pathways intersect, the potential for change will be as much a function of the organisation's history and qualitative situation as of its financial status or technological configuration.

Pursuing the mathematics of this phenomena any further would be counter productive. What has already been presented suffices to expose the issues of importance to this thesis.

Applying the equations illustrated above to the LTIME model yields a total of well over 2×10^9 possible end states for each technology's overall cost ratio. The range of these will tend towards a normal distribution centred on a mean value which reflects an average point on each variable and state parameter. This simple elucidation of the multiple solution problem serves to highlight a major limitation of the modelling process described above. On a constructive note, bounding the scope of the included variables and determining effective criteria for applying such bounds, represent clear cut opportunities for further work. Moreover, if simulation models of the type illustrated above can be initialised and their variable elements bounded in the manner discussed, the exploration of pathways can be furthered within a robust framework.

An analogous treatment of these problems is given in Beer (1966), where an exposition of some possible bounding characteristics are presented together with a discussion of the relevance of a meta-language with which to analyse them. Some O.R. techniques such as linear and dynamic programming have been developed to analyse simplistic forms of the generic problem (i.e. optimisation of simple or multiple parameter decision problems). However, many of these techniques rely on forecasting variable states and are unable to explicitly address issues of uncertain futures. A further approach is provided by Casti (1979) who attempts to describe mathematical boundaries to what is achievable given a system state S_1 and a desire to move it to state S_2 .

With regard to the further use of the model, there is a strong case for confining the model's application to exploring in more detail, but with relatively simplistic output parameters, some configurational aspect of diversity. Whilst this would not generate output as comprehensive as that found in the preceding results, it would conform to the model's role as a learning tool as outlined at the end of Section 3.2.4

4.5 An investigation into the influence of technological diversity on system cost stability.

In order to extend the use of the 'LTIME' model a simplified analysis of the effect of diversity on overall system cost stability is undertaken. The desirability of promoting stability and consistency as characteristics of technological infrastructures was discussed in Section 1.2. This element of the modelling activity directly addresses the contribution of diversity to issues of cost stability. The output parameters to be measured constitute the yearly costs accrued by both a Two Technology Strategy and a Single Technology Strategy operating under identical input cost conditions. Figure 4.4a illustrates the output cost trends for each firm. Figure 4.4b shows the cumulative cost trends for each firm type and Figure 4.4c presents the input cost profiles used during the model run.

Figure 4.4a Comparison of yearly output cost trends between single technology firm and a firm with a diversified technological base.

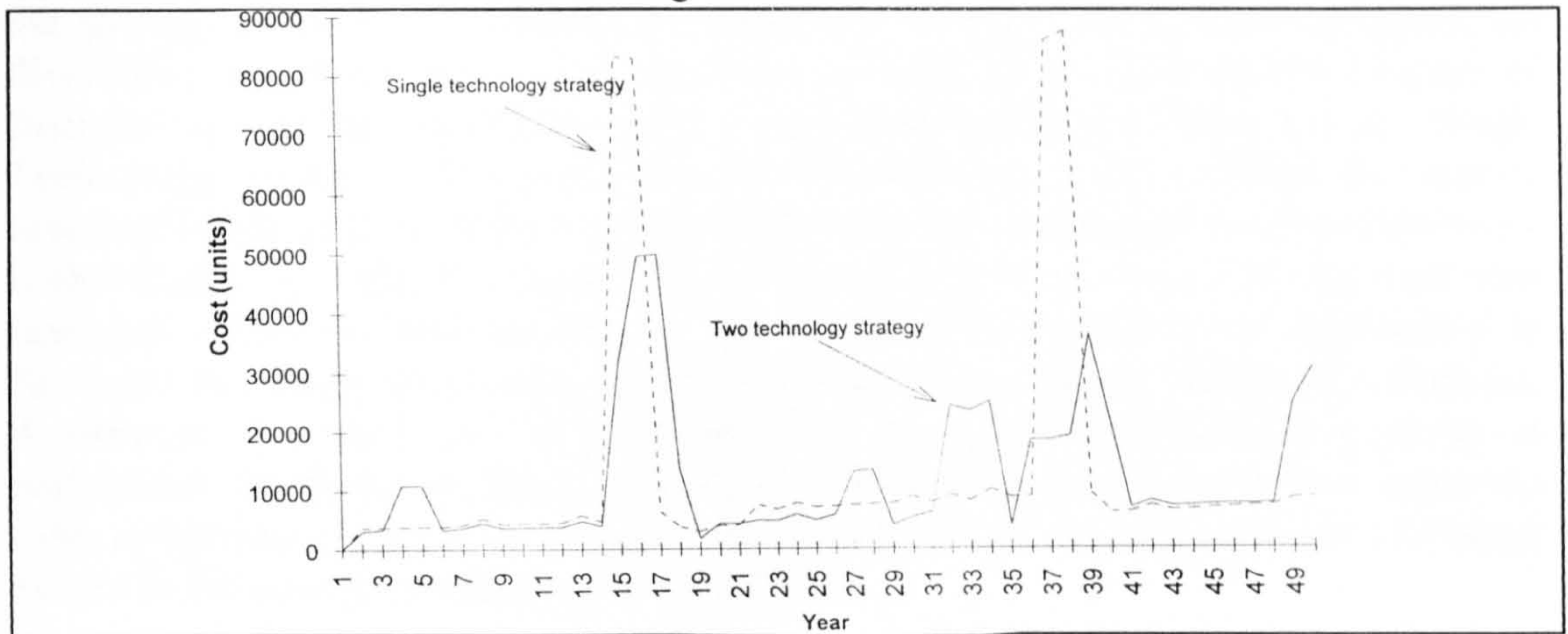


Figure 4.4b Comparison of cumulative output cost trends between single technology firm and a firm with a diversified technological base.

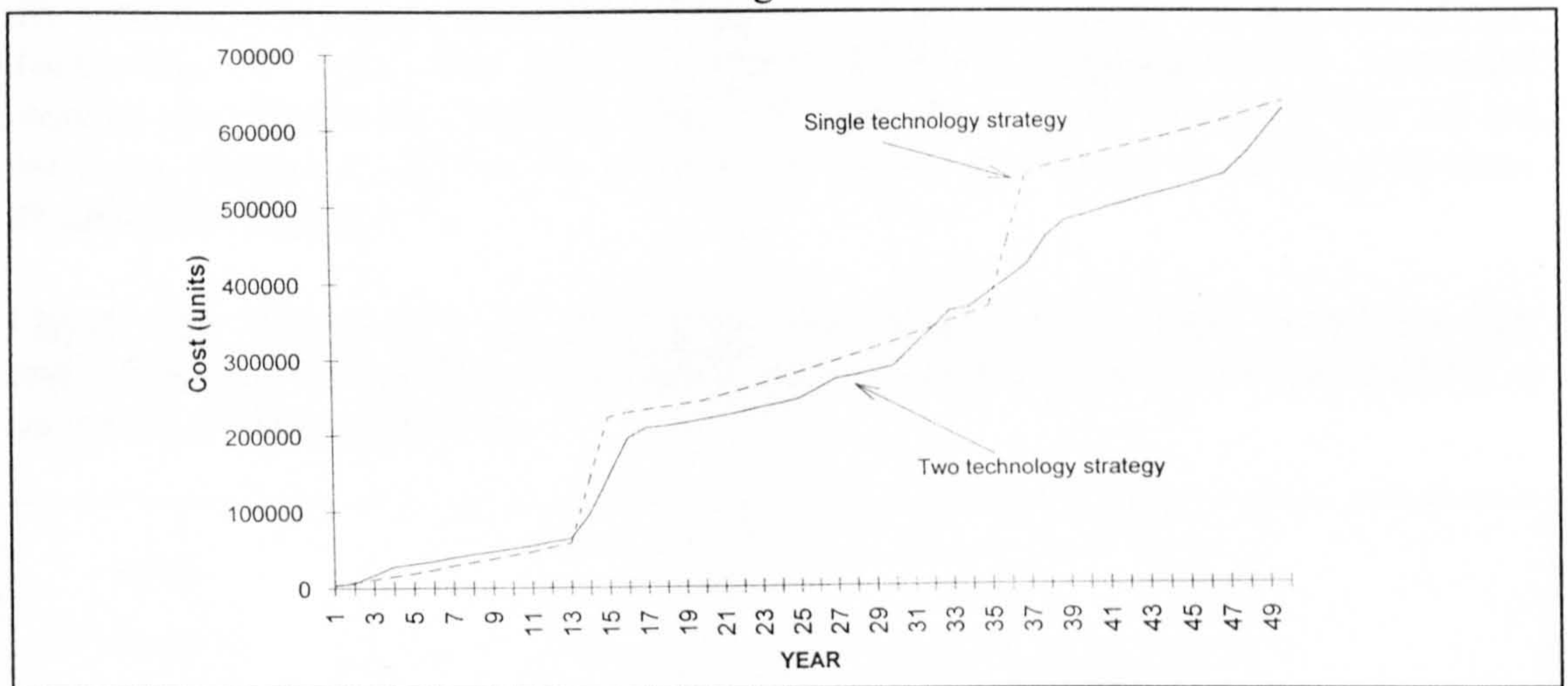
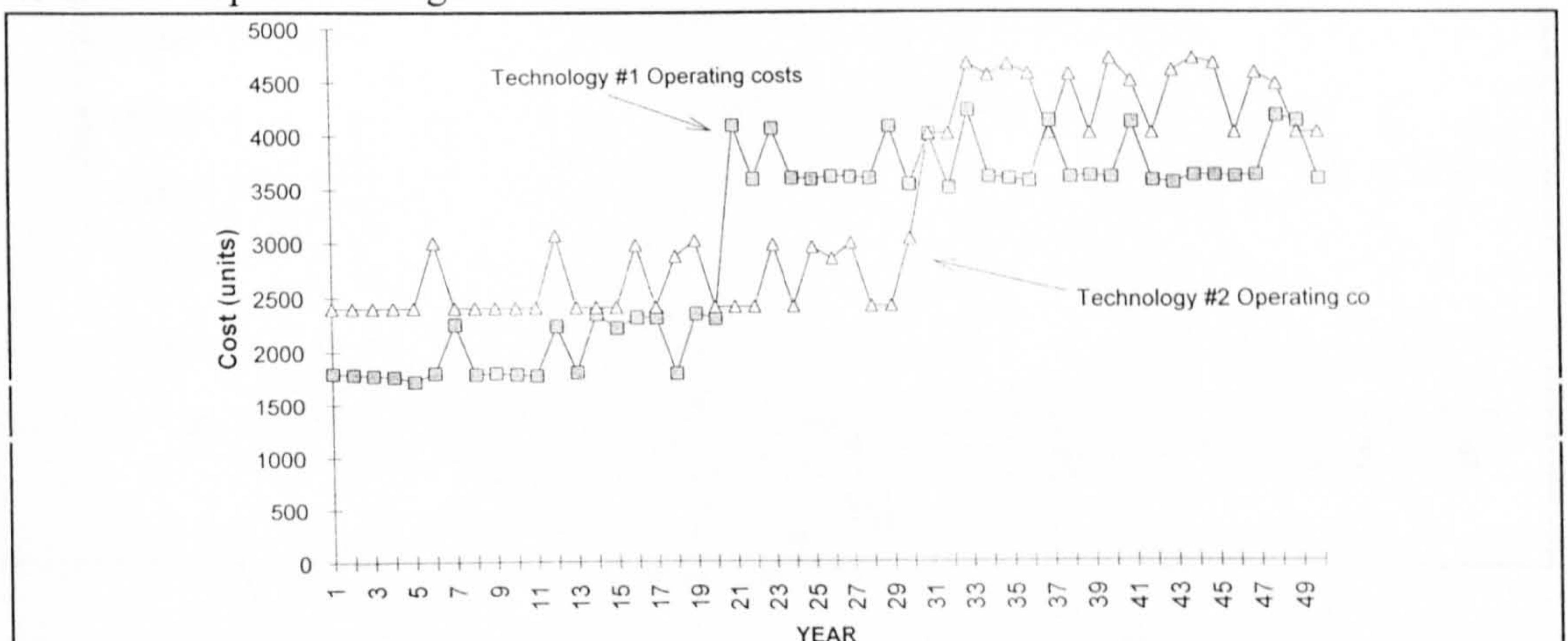


Figure 4.4c Representative cost functions used as parameters in LTIME model leading to results depicted in Figures 4.4a and b.



The results from this run clearly show the higher frequency of construction events for the strategy of diversity. When the cost trends for the two strategies are compared, the diversified strategy's yearly costs have less stability with regard to the number of fluctuations, but the variability is of a lower magnitude than those for the Single Technology Strategy. The cumulative cost trend (Figure 4.4b) confirms the relative levels of output cost variability; the diversified strategy exhibiting a less variable trend. It should also be noted that despite the differences in yearly cost accrual, the final total cumulative cost for each strategy is very similar (ref. comments on equifinality in Section 4.4). These results raise an interesting point regarding the nature of turbulence. A turbulent cost trend may be acceptable if the nature of the turbulence is regular or understood. Furthermore, the magnitude of turbulence (in this case by how much the costs differ year on year), is as important a strategic issue as the frequency of change events or the type of turbulence encountered. form.

In order to expand the investigation of the influence of diversity on total cost trends, a further run of the model was executed with the addition of two extra items of plant to the diversified strategy's technology base; one of type Technology #1, and one of type Technology #2. Total plant capacity remains unchanged, meaning that the diversified strategy now possesses more but smaller production units. The results of this run are shown in Figures 4.5 a&b. (The operating and capital cost curves are identical to those illustrated in Figure 4.4 c).

Figure 4.5a Comparison of yearly output cost trends between single technology firm and a firm with a diversified technological base. (Two additional units of plant added to inventory of diversified firm.)

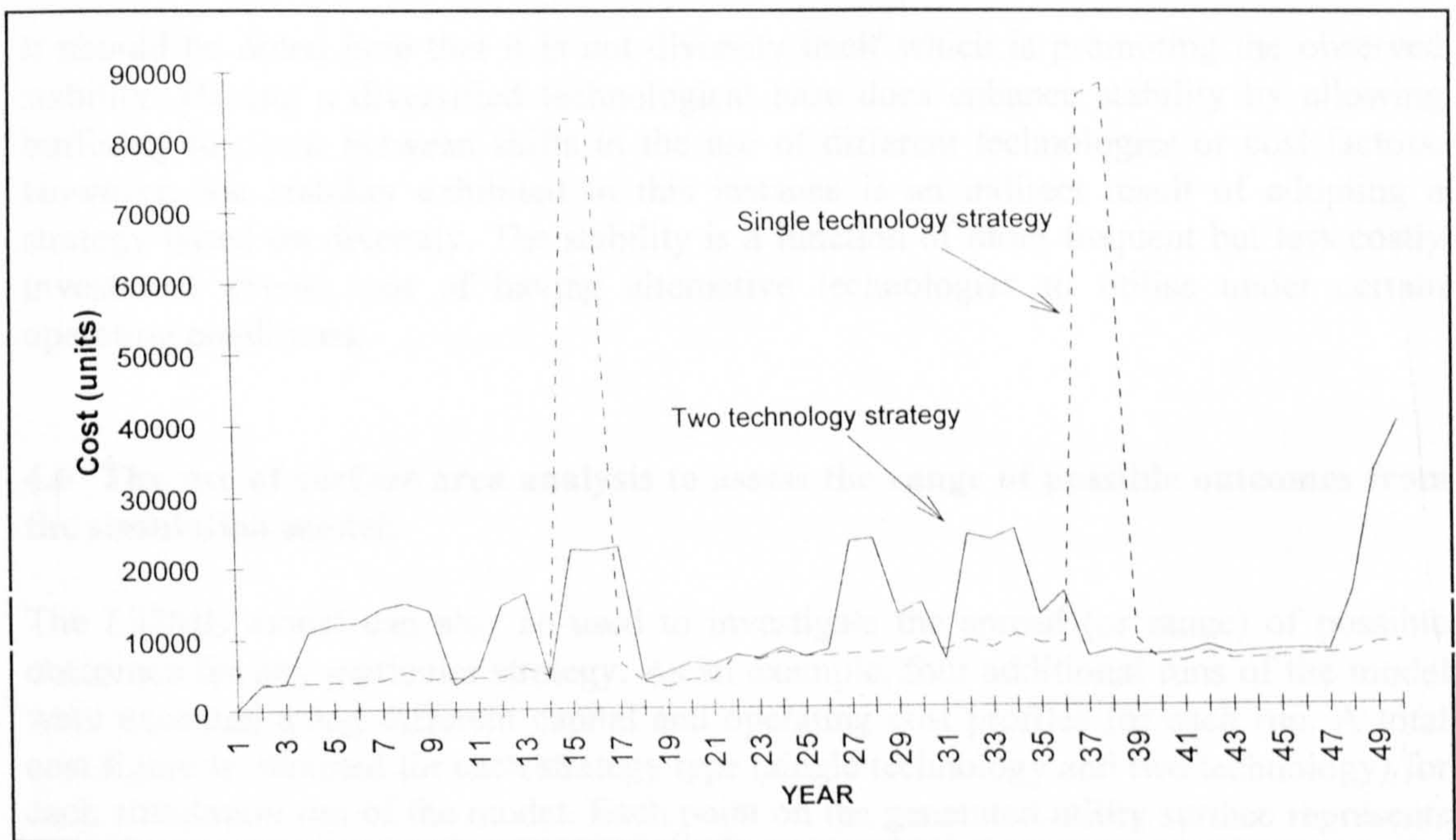
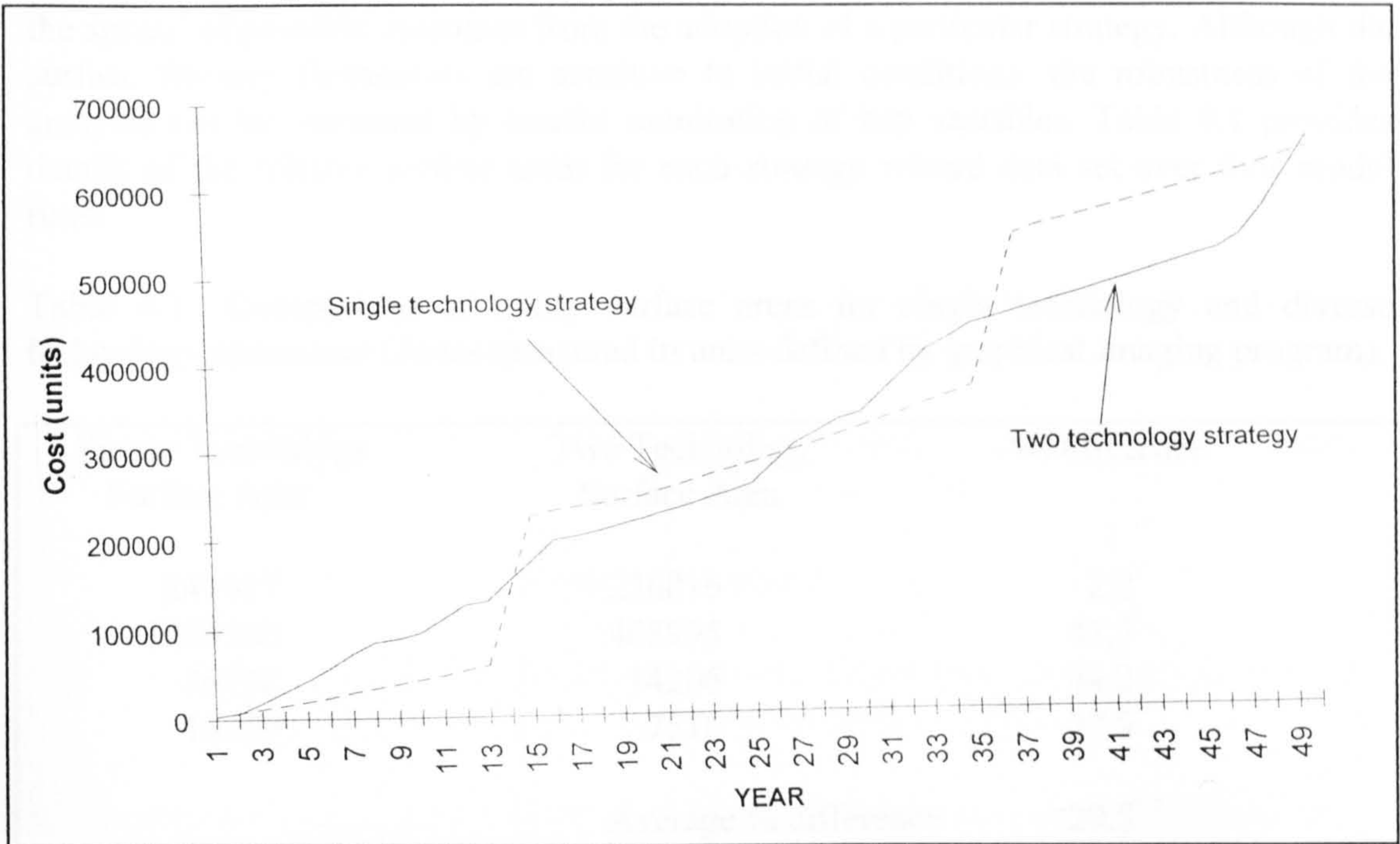


Figure 4.5b Comparison of cumulative output cost trends between single technology firm and a firm with a diversified technological base. (Two additional units of plant added to inventory of diversified firm.)



As can be seen from Figures 4.5a and 4.5b, the effect of adding more units of plant is to increase the stability of both the yearly and cumulative cost trends for the diversified firm. Such an outcome is to be expected as the frequency of construction events increases but their relative magnitude decreases.

It should be noted here that it is not diversity itself which is promoting the observed stability. Having a diversified technological base does enhance stability by allowing buffering to occur between shifts in the use of different technologies or cost factors. However, the stability exhibited in this instance is an indirect result of adopting a strategy based on diversity. The stability is a function of more frequent but less costly investment events, not of having alternative technologies to utilise under certain operating conditions.

4.6 The use of surface area analysis to assess the range of possible outcomes from the simulation model.

The LTIME model can also be used to investigate the spread (or range) of possible outcomes for any particular strategy. As an example, four additional runs of the model were executed using different capital and operating cost profiles for each run. A total cost figure is obtained for each strategy type (single technology and two technology) for each simulation run of the model. Each point on the generated utility surface represents a total cumulative cost state for each technology strategy over a 50 year operating period. In effect, the surface for each strategy characterises the potential stability of each

strategy's cost trends as surface area will be a function of the range of outcomes. For example, the minimum possible surface area would result from all points on the surface having identical values on the vertical (y) axis. Hence, the surfaces can be used to assess the spread of possible outcomes from the adoption of a particular strategy. Although the surface features themselves are sensitive to initial conditions, the robustness of the analysis can be increased by careful monitoring of key variables. Table 4.1 provides details of the relative surface areas for each strategy related data set over four model runs.

Table 4.1 Comparison of utility surface areas for single technology and diverse technology operations (Areas measured in units defined by graphical imaging program).

Single Technology Surface Area	Two Technology Surface Area	%Difference
247617	236816	2.2
1044760	408995	43.7
36738	14206	44.2
13350	7516	27.9
	Average % difference	29.5

Surface area analysis represents an additional application for the model that was developed in the previous sections. Its potential as a strategy analysis tool is dependent as much on an understanding of the processes at work within the model as it is on the generation of robust data sets. In the examples given above in Table 4.1 each run of the model utilised significantly different operating and capital cost trends as well as variations in the operating algorithm used to determine how and when available capacity is utilised. The results can therefore be interpreted as lending support to the idea that technological configurations which contain different types of plant with associated variances in cost, may lead to more stable total cost trends.

4.7 Summary and conclusions

The activities reported above demonstrate how a simulation model can be utilised to investigate some of the attributes of resilience outlined in Chapter 2. In addition, the methodological bounds of the model itself have been explored and some non-trivial limitations to its use identified.

This chapter has expanded the modelling activity initiated in Chapter 3. The motivation for developing the model concerns the potential for representing diversity in technological systems and assessing any benefits which may accrue from an investment strategy focused on elements of diversity and resilience. The findings of Chapters 3 and 4 can be summarised as follows.

1. Diversity of technological types, as represented by redundant capacity, can generate utility benefits (in terms of both total cost and cost stability) under certain cost conditions which are characterised by turbulent operating cost trends.
2. Representing technological diversity can be accomplished within a modelling framework by using a relatively simple simulation approach based on a series of linked, modular algorithms.
3. Use of the model, particularly with regard to assessing the value of output data, is problematic due to a number of factors:
 - a) Difficulties in identifying suitable parameters against which to measure utility.
 - b) The emergence of multiple solutions.
 - c) Complexity of interactions between parameters, particularly those used to characterise technology types, are difficult to assess.
4. Increasing the complexity of the model does not serve to clarify the issues or provide further insights. Rather it exposes both methodological and technical weaknesses without significantly contributing to the usefulness of the output.

Whilst the results from the modelling activities generate as many questions as they do answers, their contribution must be considered in the context of the study as a whole. Each of the findings listed above will contribute towards a more general discussion of the modelling activity in Chapters 8 and 9. Aspects of the modelling activity findings will also be used to support the conceptual framework discussed in Chapter 10. Here, the relevance of analysis technique and system attributes are seen to be bounded by strategic, decision issue and other parameters.

This chapter completes the modelling activity stage of the research. Chapter 1 presented a broad outline of the study and isolated three core issues pertaining to the study of technology planning; modelling, strategies for addressing uncertainty, and the attitudes of modellers. Chapters 3 and 4 have addressed a combination of the first two of these issues. The following chapters (Chapters 5-7) are concerned with a combination of all three. The research agenda was derived from an interdisciplinary approach to problem identification and formulation. Having pursued one element of this agenda to a stage where useful methodological and practitioner results have been identified, the thesis now moves on to consider an alternative aspect of the primary research question.

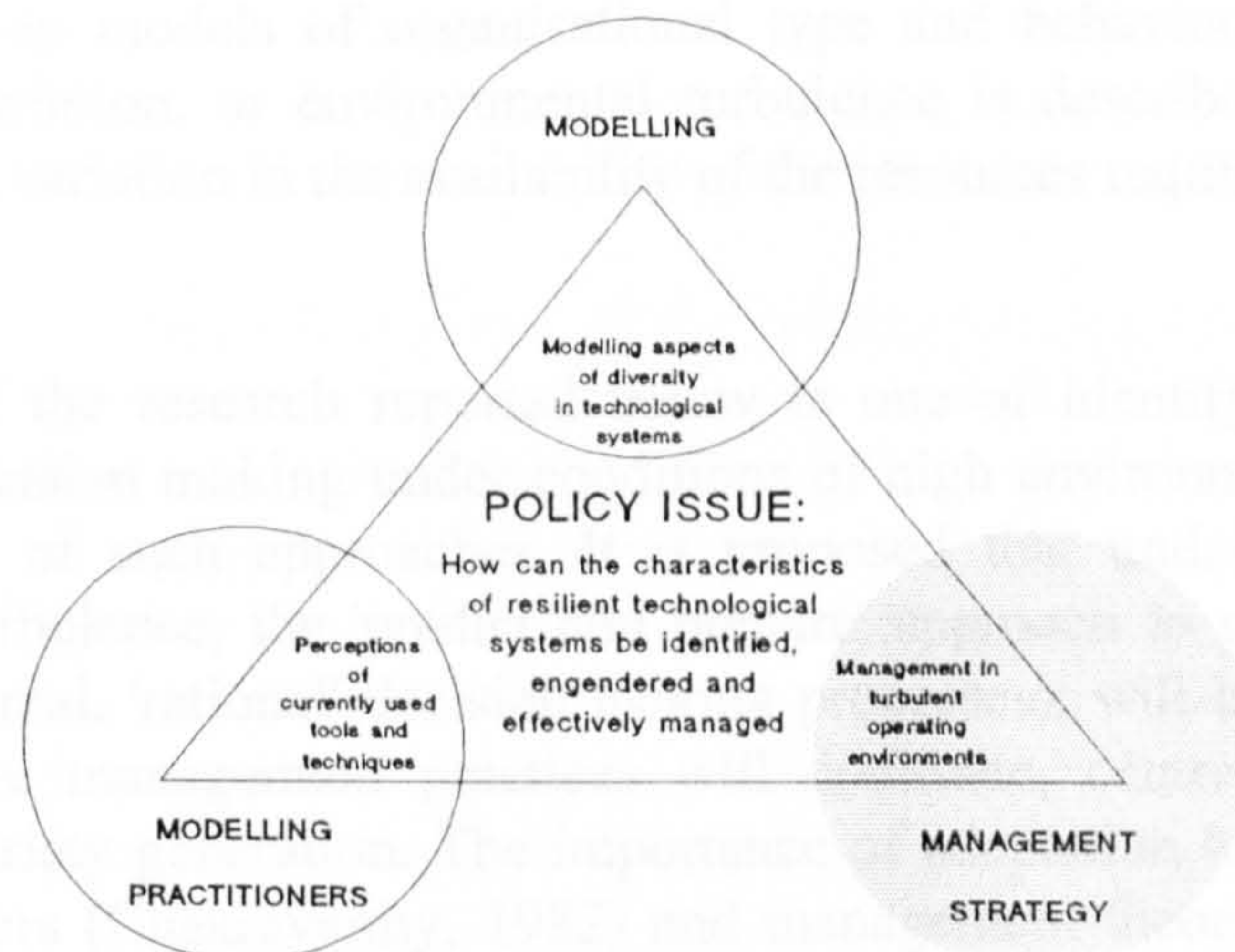
CHAPTER 5

EVIDENCE FOR ALTERNATIVE STRATEGIES IN TURBULENT OPERATING ENVIRONMENTS: A CASE STUDY OF MANAGERS AND DECISION SUPPORT PRACTITIONERS IN ISRAEL

5.1 Introduction

Chapter 2 presented a general discussion of resilience as a characteristic of strategies with which to address uncertainty was presented. Chapters 3 and 4 have demonstrated the difficulties of developing a modelling approach to planning and managing these phenomena. In order to expose the characteristics of successful approaches to handling uncertainty, this chapter outlines the design and execution of a survey carried out amongst modellers and decision makers operating under turbulent operating conditions. Figure 5.1 highlights the contribution of this Chapter to the overall research programme.

Figure 5.1 Focus of investigation for Chapter 5.



The significance of focusing on a rapidly changing environment is derived from the discussion of the nature of uncertainty presented in Chapter 2. This posited that the potential for multiple possible futures provides a framework within which uncertainty can be formalised as unforeseen change. Strategies which are designed to address uncertainty thereby focus on '*providing the potential for change in order to adapt to diverse environments.*' (§ 2.7.1). The contribution of flexibility (the potential for change) and adaptivity (executing such change) to resilience as discussed in Chapter 2, constitute the main feature of this element of the research. Developing this proposition within the context of assessing resilience provides the basis for the study presented below. If strategies for addressing uncertainty via adaptiveness and diversity are to be identified, they are likely to be found under conditions of high operating environment turbulence where the 'predict and prepare' approach is least likely to succeed. Such an environment is characterised by fluctuations in many performance significant variables and high levels of doubt concerning future economic, social and political trends.

As with the rest of this research programme, the focus of attention is within a technology planning context and the above outlined points relate primarily to such a framework. Contextual relevance was accomplished in the survey by accessing individuals concerned with technology analysis or investment and concentrating on organisations which make sizeable technology investment decisions.

Current literature on these issues include contributions by Simon (1960) and Cyert & March (1963), who both suggested that organisations avoid uncertainty by introducing stabilising behaviour which include the smoothing and buffering of environmental fluctuations. Evidence for such behaviour has come from, amongst others, Lev (1975) who used port-folio theory as a basis for investigating and confirming these claims. The management style which is identified in the empirical studies as being suited to a turbulent operating environment is conservative, placing emphasis on both contingency planning and minimising risk exposure. The determinant of this approach is often associated with an apprehension regarding possible losses / mistakes. Organisational theory has long associated variations in environmental measures with organisational structures and actions. For example, both Strategic Choice Theory (Child, 1972) and Organisational Ecology (Hannon & Freeman, 1977) view environmental variability as a central construct in models of organisational type and behaviour. Such longitudinal environmental variation, or environmental turbulence is described by Dess & Beard (1984) as being a variation in the availability of the resources required for organisational survival.

The objective of the research reported below is one of identifying both alternative approaches to decision making under conditions of high environmental turbulence and the determinants of such approaches. It is proposed that under conditions of high environmental turbulence, the 'predict and prepare' approach to planning (including a reliance upon formal, 'rational' decision making processes), will be found ineffective. Hence, alternative management practices will dominate, centred around flexibility, adaptivity and variety generation. The importance of adaptation has been characterised by both researchers (Chakravarthy, 1982) and management theorists (Peters, 1989) as crucial to organisational survival. It should be noted that the study is not concerned with the measures of *perceived* environmental turbulence as covered by Duncan, 1972 and Downey et al, 1977. Rather it is focused on the relationship between the experience of environmental variance and the subsequent use of alternative approaches to decision making and management.

Emergent from this discussion are three issues which drive the data collection process:

1. What particular sources of change are of concern to managers operating under conditions of high environmental turbulence.
2. What strategies to combat change are perceived to be beneficial by managers operating in a turbulent environment.
3. What role do formal analysis techniques play in such strategies.

Both decision makers and decision support / modelling practitioners were included in the study so as to allow information from two perspectives on the decision making process to be assembled.

5.2 Identification of survey population: Environmental volatility in Israel

In order to examine these propositions a project was initiated during the Summer of 1990 involving a questionnaire and interview based survey of large organisations. As a broadly bounded information gathering process the survey was designed to inquire into those formal and informal policies, strategies and techniques utilised by management to address uncertainty.

The criteria for selection of a survey population needed to be focused on the existence of a turbulent operating environment. In detail this should entail unpredictable fluctuations in key operating variables (financial, cost, labour, economic etc), and if possible the occurrence of 'surprise' events which effect a shock to the economy in general. It proved difficult to locate any formal measures of actual environmental volatility. Therefore, an essentially qualitative assessment of possible target populations was carried out with the aid of a general literature search and background material from various sources such as the Economist Intelligence Unit's Annual Reports.

Focusing on the selection criteria, one of the prospective candidates was the State of Israel. The influence of American and European work practices in Israel are readily evident, the economy as a whole being orientated towards these and the domestic markets. In addition, a majority of the population are of European origin, and this trend is accentuated with relation to decision makers and university graduates. The above factors, when combined with the availability of a study grant (see acknowledgements), and the existence of a particular structural relevance to European industry, made Israel the final choice for providing a target environment for the survey.

As an operating environment for business, commerce and the public sector, Israeli economic and socio-political structures exhibit a high degree of instability and turbulence (Law-Yone, 1991). This takes many forms including:

- a) Social change:** Fluctuations in population levels and abilities. Range of socio-cultural elements amongst population. Military service requirements.
- b) Economic/Financial change:** Exchange rates, inflation rates, interest rates, tax structures and financial legislation all prone to quick and large scale change.
- c) Political change:** Government influence in business very pronounced. Personnel changes amongst departmental ministers and quango members is frequent. Government policies on the economy erratic. Geo-political influences on business important.
- d) International elements:** Threat of war never far off. Trade agreements and boycotts

influence ability to market etc.

In order to illustrate some of these influences, the following figures show trends in several key variables which directly impact on the efficiency and effectiveness of planning activities in Israel. Where relevant, these are shown together with figures for the U.K. to illustrate the relative level of turbulence experienced by Israeli decision makers.

Figure 5.2
Immigration into Israel (1948-90)

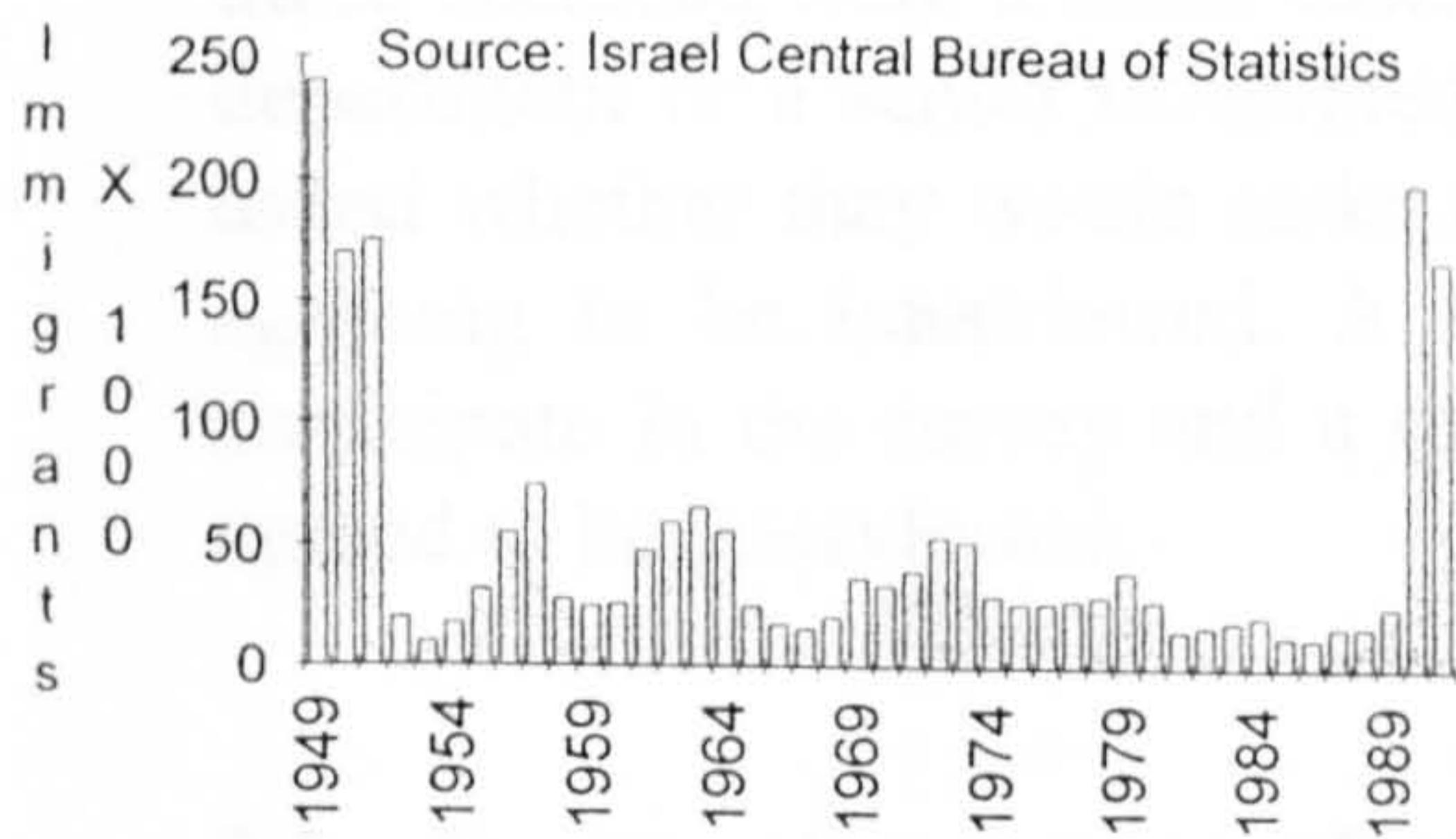


Figure 5.3
Shekel / Dollar exchange rate

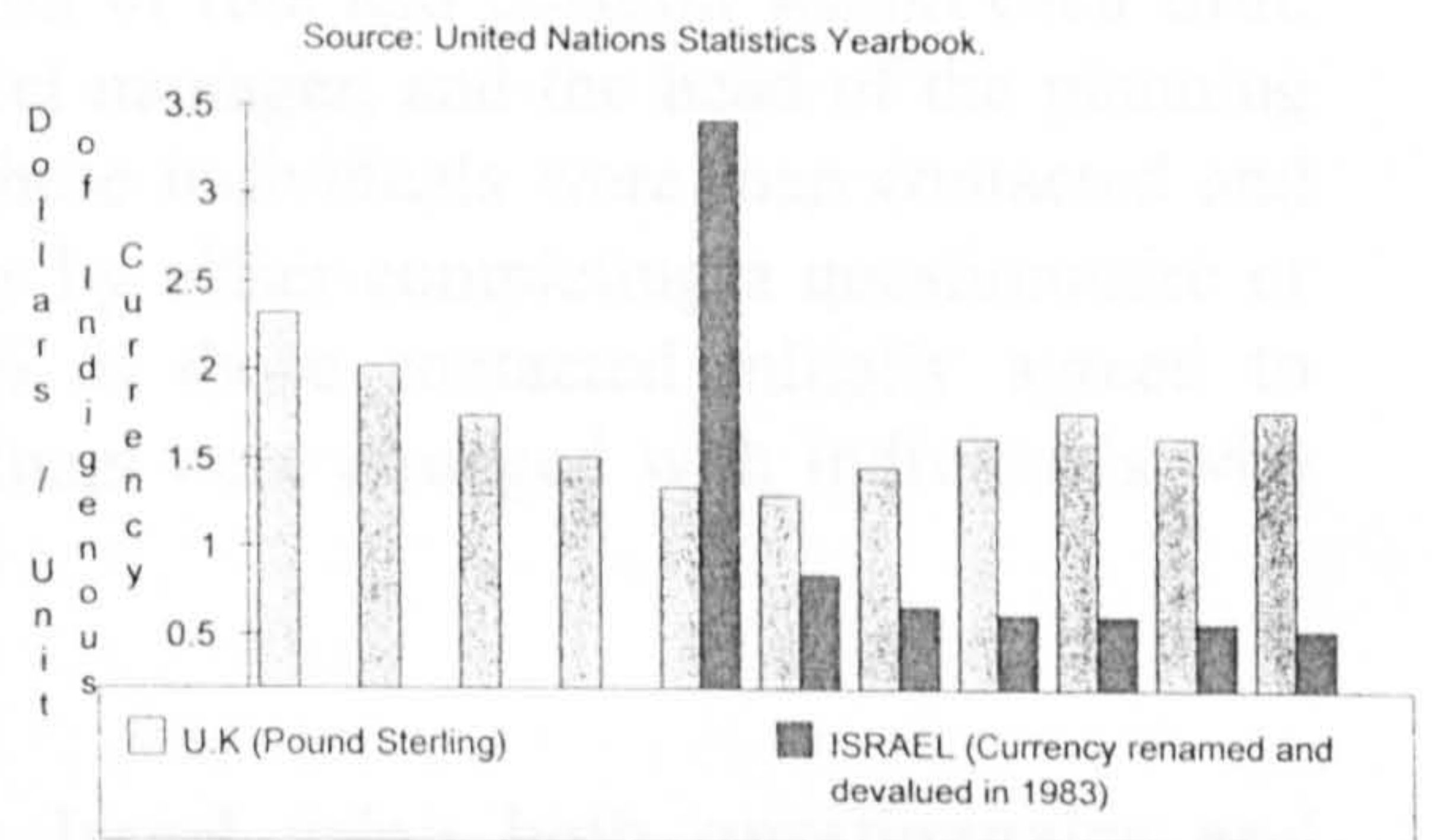


Figure 5.4
Share price changes over previous year.

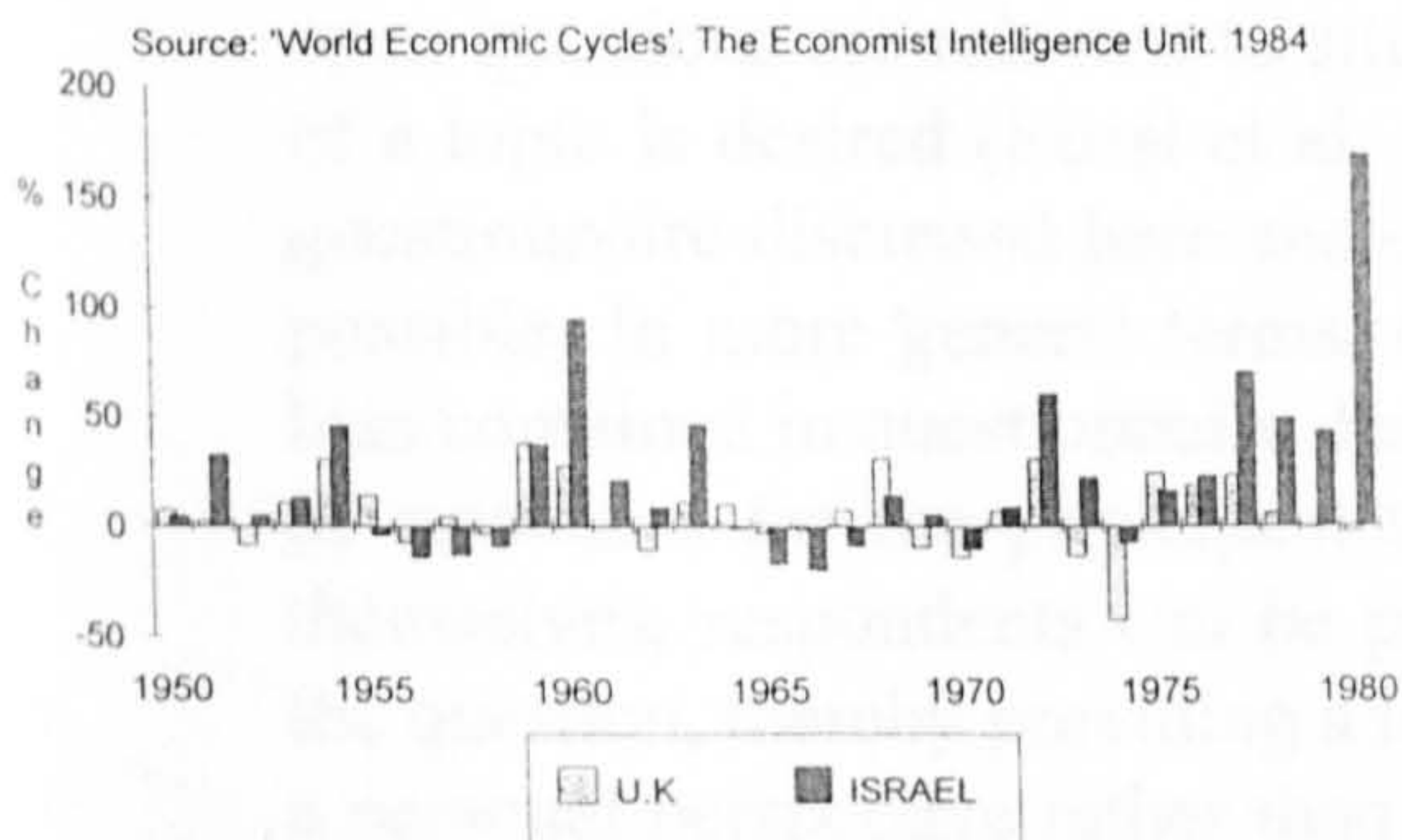
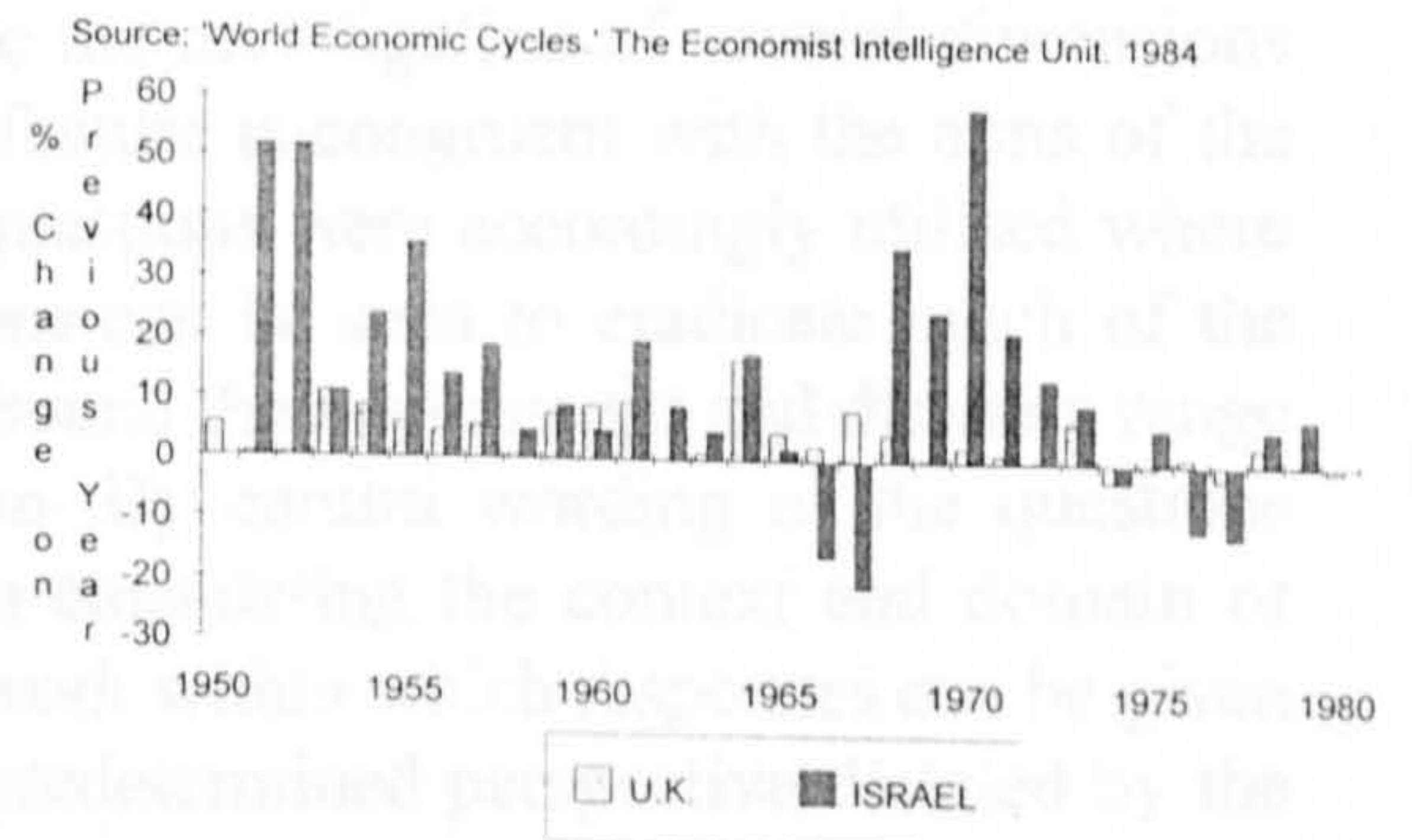


Figure 5.5
Fixed investment changes over Previous year.



The target population for the survey consisted of both decision makers and decision support staff occupying senior or middle management positions in medium to large corporations. Discussions with research groups in Israel suggested that a relatively low response rate from a questionnaire based survey could be expected. In addition it was considered that individuals in decision making positions would be unlikely to respond to a 'cold' postal questionnaire, but would react more positively in a face to face interview situation. Accordingly, both questionnaire and interview methods were utilised for information collection.

Identification of target companies as potential sources of respondents was achieved by isolating forty of the top 100 industrial concerns using a weighted index of turnover and number of employees. Two potential respondents were targeted from each company. Whilst job titles appeared to be little indication of role and position within each firm, those accessed were a board member or project manager, and the head of the planning department or a senior investment analyst. These individuals were then contacted and asked whether they would assist in the survey by either completing a questionnaire or agreeing to be interviewed. A total of 75% of those contacted initially agreed to participate in the survey and a series of meetings were arranged with individuals who agreed to be interviewed.

5.3 Design of a survey of managers in Israel using both questionnaire and interview techniques.

Questionnaire design focused on developing an elicitation based framework within which respondents were encouraged to propose answer sets rather than choose from a pre-determined list of responses. This open-ended question formulation was intended to act as an issue portrayer as well as a vehicle for the collection of specific data on certain aspects of the respondents role and activities. Dohrenwend & Richardson (1963) present a debate concerning the relative merits of open and closed questions and whilst Sudman & Bradburn (1974) reported no overall superiority for either question style, subsequent research by Schuman & Presser (1978) concluded that selection of one or other of these question forms should be determined by the type of information required. In particular, open questions are relevant to situations where the investigation of several dimensions of a topic is desired (Rossi et al, 1983). This feature is congruent with the aims of the questionnaire discussed here and open ended questions were accordingly utilised where possible. In more general terms, open questions can be seen to eradicate much of the bias contained in questionnaire designs which bound the response set and dictate a range of responses for the participant to select from. By careful wording of the questions themselves, respondents can be prompted into considering the context and domain of the question, thereby providing a looser framework within which responses can be given a personal perspective rather than adopting a predetermined perspective dictated by the questionnaire designer.

There were a number of contextual and language specific problems associated with the questionnaire development (The questionnaires were presented to respondents in both

Hebrew and English), and these were addressed by exposing drafts to proof reading by bilingual practitioners in the fields of economics and the social sciences. In detail, the attributed problems revolved around 3 distinct issues;

- 1) A specific terminology and jargon based language set has developed in the U.K and other countries relating to general business techniques and phenomena, the use of which in an Israeli context needed careful preview.
- 2) Several key words were identified, any misinterpretation in the meaning of which would have made the response set unusable. (Problems associated with differences in questionnaire interpretation have been highlighted by amongst others, Payne, 1951).
- 3) The tone and temper of the questionnaire needed to reflect the existence of a more informal management style in Israel. (This requirement was instrumental in determining the loosely defined structure of the questionnaire).

Piloting of the questionnaire was undertaken with the co-operation of a group of managers from small commercial and industrial enterprises in the Jerusalem area. This process both highlighted the problems noted above and, through discussion with the pilot group, provided some indications for possible solutions. Three distinct measures were taken to redress the difficulties :

- (i) Cross checking the use of jargon and discipline specific terminology with the pilot group.
- (ii) Supplying a brief definition of some key words and phrases on the cover sheet of the questionnaire.
- (iii) Ensuring that the tone of the questionnaire was as casual and unofficial as possible without losing the professional inflection which it was hoped would increase the quality of responses.

The semi-structured interviews were conducted in English and followed an elicitation framework which prompts interviewees to develop and discuss a 'pathway' of issues in response to a number of core questions. This approach is particularly beneficial under circumstances where a broad range of issues are under investigation and there is a desire to build up a network of interacting opinions and attitudes (Lemon, 1991). The interview process involves the interviewer making detailed notes regarding both the substance and structure of responses. Analysis of the transcripts entails collating responses across core questions and identifying commonalities of both subject matter and the way in which comments are structured in a commentary.

In order to provide a framework for the interviews, four 'Issue Templates' were developed which were intended to both bound the conversation and constitute a common frame of reference for analysis purposes. Accordingly, the interviewees were invited to consider a recent event, extraneous to their company, which had effected a high degree of surprise on management. Subsequent to the identification of a suitable event, the interviewee was guided through a 20-30 minute discussion. The template structure (see Appendix 2) was characterised by a primary / secondary / tertiary query process which took key issues relating to the event and followed lines of debate through a predetermined path.

5.4 Results of the survey of Israeli managers.

As mentioned above, job titles amongst the response group provided little information regarding the individual's role and position. Individuals who responded represented a wide range of positions within their companies and represent a comprehensive cross section of senior Israeli management. Average residency in their current position was over 5 years.

The results from the questionnaires and interviews are presented in two forms. Firstly, an analysis of that evidence which lends itself to graphical or tabular presentation is given. The degree and extent of statistical analysis applied to the data was consciously bounded (i.e. restricted to simple distributions and groupings) for the reasons stated above concerning the types of information required. The second element of the results comprises comment on the more anecdotal evidence collected during the interviews. Content analysis and other forms of qualitative data assessment for this type of information were not applied in this case. The discussion surrounding these data is therefore heavily reliant upon the incidence of specific comments or observations across several respondents.

The data in the figures and tables below constitute responses from 55% of the individuals who initially agreed to complete a postal questionnaire, and from 90% of those who agreed to participate in a face to face interview. Twenty potential respondents initially contacted by phone were either unable or unwilling to participate in the survey at all. The final response count comprised 33 completed questionnaires (including those realised as part of the interview process), and fourteen interviews.

5.4.1 Data collated from the questionnaire returns.

The questionnaire responses revealed that a wide range of factors are considered as sources of turbulence by the response group (Figure 5.6). In particular there was an emphasis on the influence of government activities. A particular characteristic of this response set is that seven out of the nine categories represent factors which fall outside the ability of the organisation to effectively control.

Figure 5.6 Identified sources of influence on the organisation's operating environment.

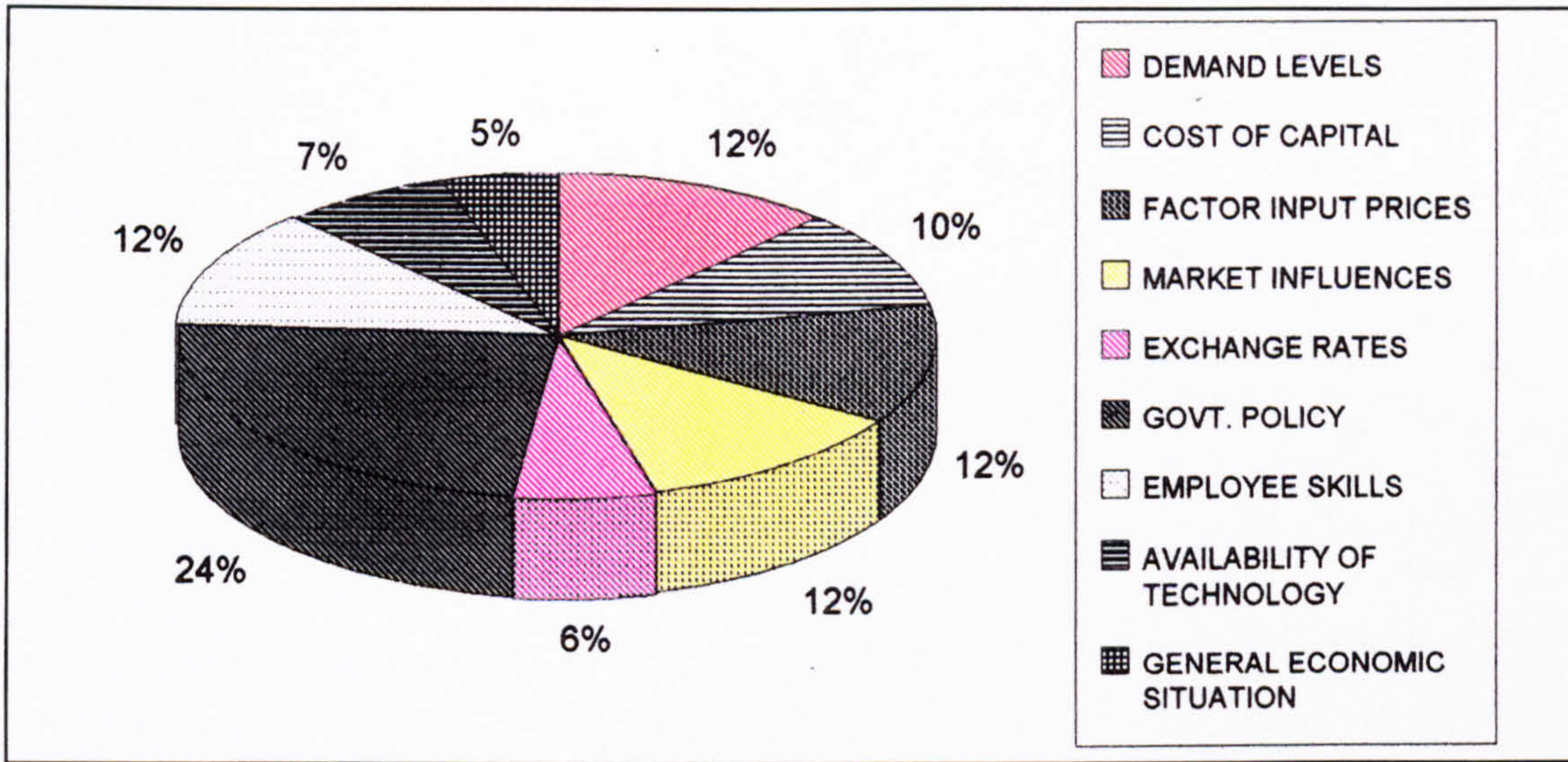
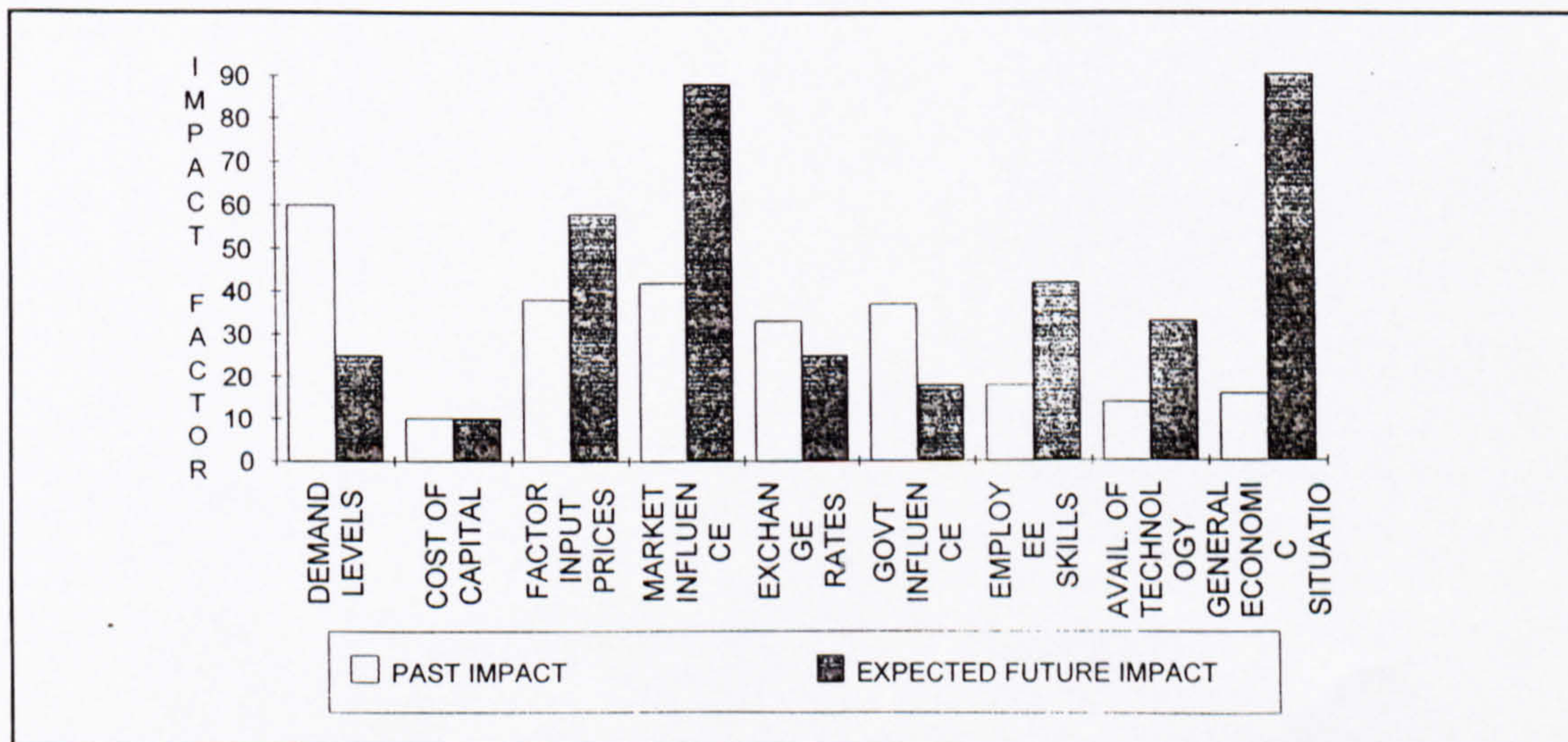


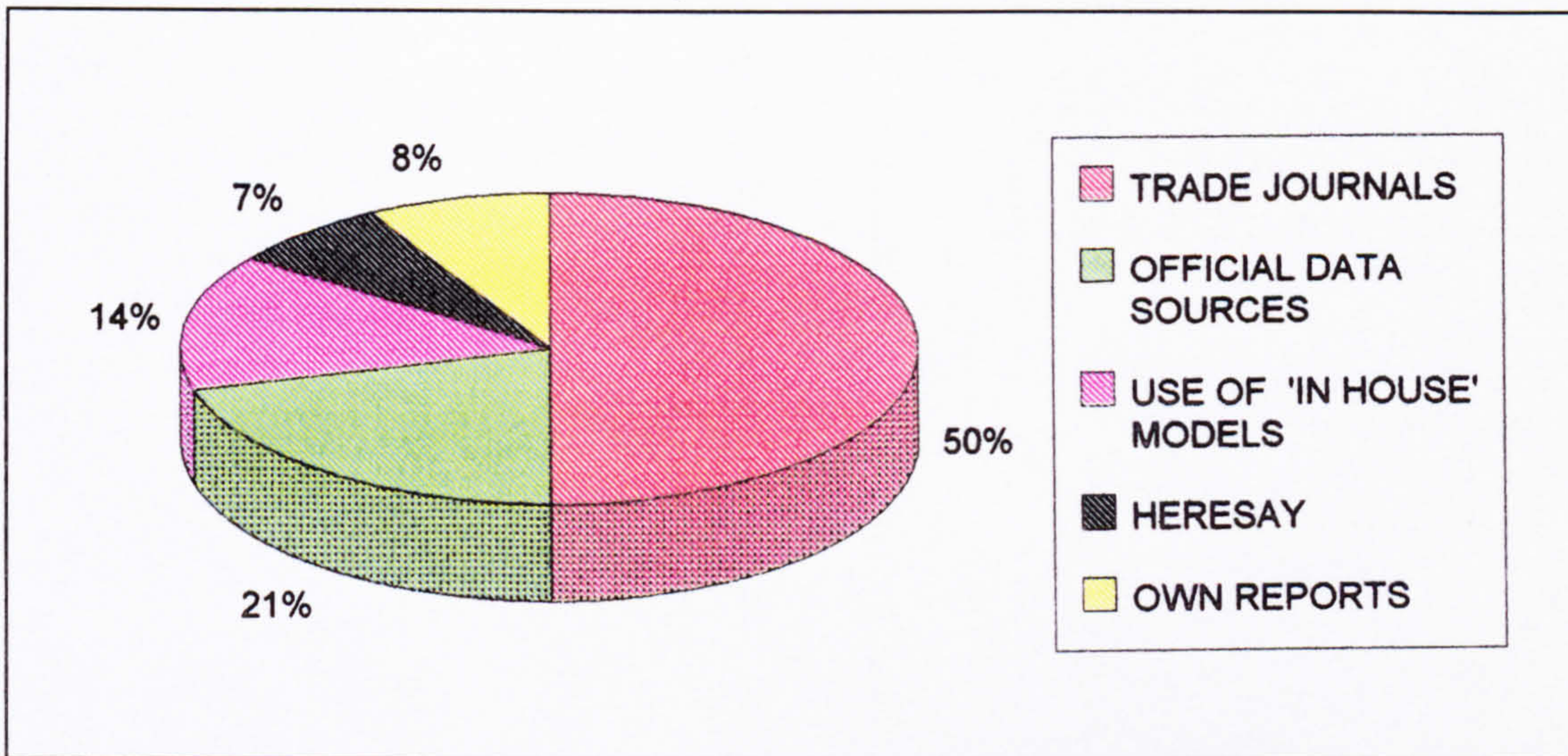
Figure 5.7 provides some evidence for the existence of variable appreciations of levels of turbulence within the response group and shows the past and expected future intensity or level of volatility associated with each of the influences specified in Figure 5.6. This data set is derived from a series of questions which asked respondents to comment upon three parameters (frequency, magnitude, and impact of change events) influencing a number of elements of their organisation's operating environment. Respondents selected from Low, Medium, and High for each parameter. An ordinal measure of each element's influence (i.e. demand levels, cost of capital etc) was then assessed by grouping the responses and applying a weighting factor to each category. The measurement scale for Figure 5.7 is therefore best interpreted as describing the relative influence of each factor.

Figure 5.7 Past and future expected level of volatility associated with those elements identified in Figure 5.6.



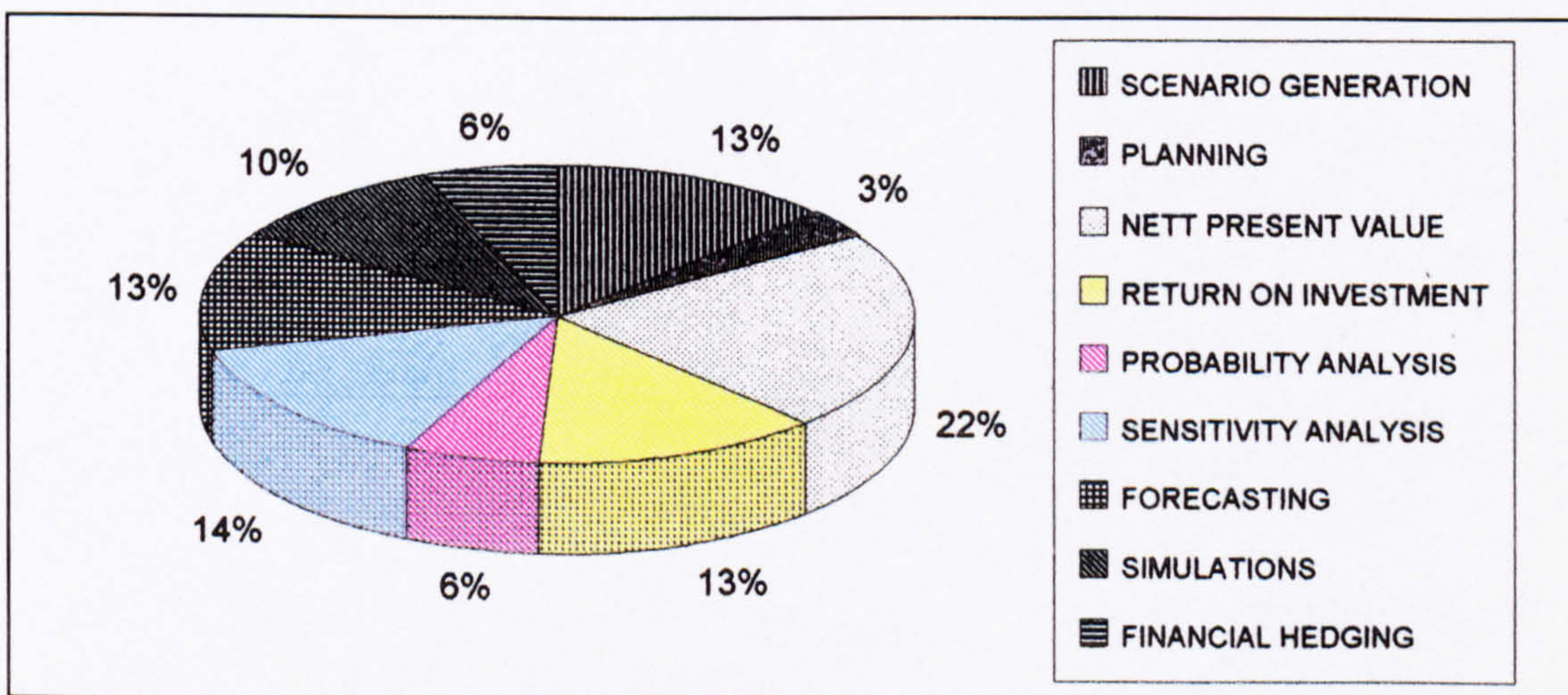
With regard to the degree to which a predict and prepare paradigm is influential amongst the respondent group, analysis of the questionnaire responses shows that only eight of the 28 firms represented attempt to forecast key variables. This finding raises questions about the experiences of these organisations with such methodologies and the alternative planning paradigms which may be in place. Details of sources of information on the key influences depicted in Figure 5.6 are shown in Figure 5.8.

Figure 5.8 Sources of information accessed by respondents..



With regard to those strategies and techniques which are utilised to combat uncertainty, 86% of those responding to the questionnaire identified at least one such method, 78% identifying 2 or more. However, when asked what additional methods they were aware of, only 30% of respondents were able to proffer suggestions. Figure 5.9 shows the frequencies with which specific strategies / techniques were identified as a ratio of total positive responses.

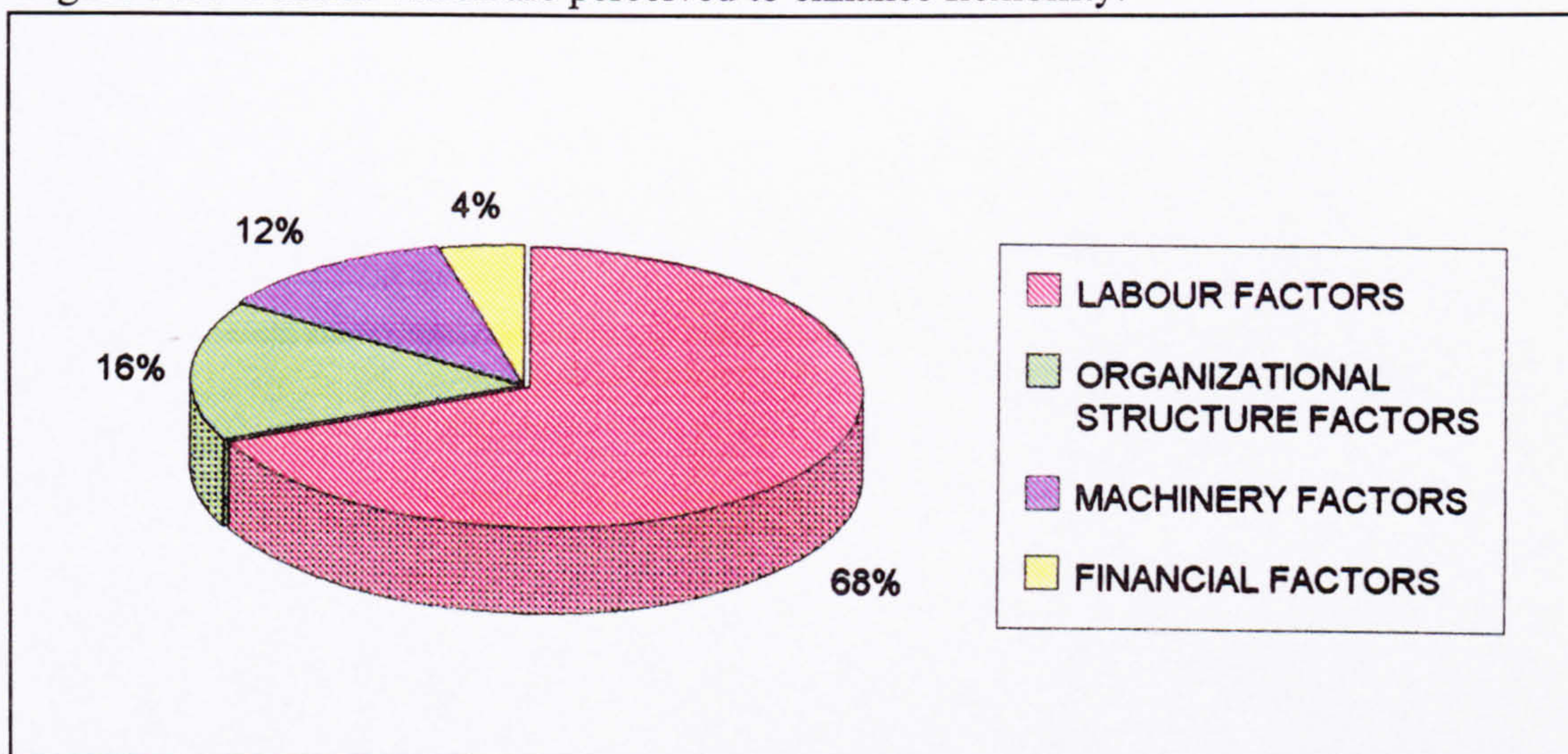
Figure 5.9 Mention of specific strategies or techniques used to combat uncertainty.



The emphasis of the response set illustrated in Figure 5.9 is on formal analysis techniques. Formal, in that they are directly attributable to published, structured assessment processes with recognisable common characteristics. If this set of techniques was placed before a group of U.K. managers, they would recognise most if not all of the stated tools. There is a paucity of human centred or process orientated replies and none of the respondents mentioned any alternative techniques or policies to those presented. Analysis of the total response set (including interviews) however, revealed that the data shown in Figure 5.9 represent the 'official' approach to handling uncertainty. The interview data illuminate an informal agenda with an alternative focus which is discussed in more detail below.

Pursuing the issue of possible alternative strategies to combating uncertainty, respondents were asked about elements or characteristics of their organisation which could be identified as enhancing its flexibility. The replies have been grouped into four main divisions and the resultant breakdown is shown in Figure 5.10.

Figure 5.10 Factors which are perceived to enhance flexibility.



Human factors such as training, education and employee skills were the main elements of the largest response set (labour factors) but it is possible to further aggregate this data set into soft and hard elements - Labour/Organisational and Machinery/Financial respectively. This disaggregation process yields an 84% unprompted response identifying soft factors as being central to the flexibility of the respondents organisation.

5.4.2 Data collated from the interview programme.

The following information was collated from a series of 14 semi-structured interviews. In order to indicate the robustness of the data from which the following statements are derived, a threshold was applied to the incidence of remarks on each subject. Hence, unless otherwise stated, each of the following points were mentioned by at least 10 of the 14 interviewees.

Responses to the issues contained in interview templates 'A' and 'B' focused on the viability of scanning as a means for anticipating environmental changes. The response group were of the opinion that formal scanning activities could have identified the surprise event which they had been asked to consider. However, the cost of undertaking such procedures was prohibitive given the nature of many environmental changes, the onset of which can not be detected. The nature of contingency planning for the surprise event being considered (the type of event differed across respondents) was found to be informal and reactive. There was little indication of any formal, structured plans of action which were initiated upon the event's occurrence. Rather responses were characterised by reference to the robustness of the organisation's current operating procedures. Specific elements of the reaction to the surprise event reflected a consultative process with little formal modelling or analysis.

With regard to the planning process (interview template 'C'), initial decisions regarding investment or other plans were reported as being selected for their ability to be refined or altered at future points in time. Justification for such a strategy was often on the grounds that it allowed a sequence of decisions to be made which allocate and dedicate resources at different time intervals, promoting flexibility. Some attempt was made during the interviews to quiz the respondents on the actual use made of formal planning methods as part of the decision making process. Responses to this query suggest that it is 'gut reaction' or 'what felt right' which drives many decisions with regard to both day to day and longer term management decision making. Indeed, several of the decision support staff interviewed expressed disillusionment with the weight given to their analyses by decision makers. Another feature of this response set was the emphasis placed on consensus and achievability when considering proposed investment or other plans. Ensuring that the adopted course of action carried the support of as many relevant managers as possible was given by a majority of interviewees as a criteria for option selection.

Interview template 'D' guided the interviewees through a discussion on the resilience of their organisation. Without exception, respondents characterised their organisation as being resilient with respect to environmental turbulence. The determinants of resilience were considered to lie in both the management style and a series of human centred attributes such as employee flexibility and training. When questioned further on this style of management respondents fell back to the position that a great deal of their time was spent talking to other managers and employees, eliciting information about how the organisation was coping with problems such as manpower shortages, machinery breakdowns, and financial difficulties. Data on the promotion of such characteristics indicate that little is done to positively engender flexibility and adaptivity. However, employees are expected to turn their hand to any task which requires fulfilling and were praised for their ability to act as replacement for their work mates and even on occasion, for their bosses.

5.5 Discussion of survey results

Combining the evidential data from the questionnaire and interview sources enables a case specific characterisation of management under turbulent operating conditions. The particular sources of turbulence which are of concern to the organisational actors involved in the survey are mainly outside the scope of the organisation to affect. A similar finding was reported by Naude et al (1990) in a study of managers in South Africa. Furthermore Israeli managers perceive variances in the levels of influence which each source of environmental variation has had and will have on their organisation. However, no discernible trends are evident to suggest that any one source either has been or is expected to be dominant.

Formal planning processes and structured approaches to combating uncertainty appear to be subordinate to other aspects of management as influences on decision making and control procedures. The use of forecasting is not widespread and whilst questionnaire responses suggested that a range of formal techniques are used to address uncertainty, the interviews revealed an alternative approach based on flexibility and a consultative management style. These two response sets appear to be dichotomous; the one providing evidence for a formal, planned approach to addressing uncertainty, whilst the other provides evidence for a more informal approach which relies on organisational resilience. A possible explanation for the variance in responses may lie in the wording of the relevant inquiries. The questionnaire referred to 'techniques for combating uncertainty' whereas the interview process relied on respondents to suggest processes by which the organisation avoided the disutilities associated with surprise events. Hence the questionnaire responses refer to conscious efforts by the organisation to plan for uncertainty whilst the interview data are focused on how the organisation responds to change. It is worth noting that none of the interviewees commented on the effectiveness of their formal planning processes when asked to identify determinants of the organisation's resilience.

Although the use of formal analysis techniques in Israel is currently growing (Aharoni, 1988) the evidence presented above suggests that its integration into the decision making process is restricted. Several authors have highlighted the use of formal analysis as conveying rationality and legitimacy (Edelman, 1985; Feldman & March, 1981). Other institutional theorists make the point that organisations promote the aura of rationality as a legitimate framework for decision making as external sources of support would treat anything else with suspicion. Quinn (1980) suggests that formal analysis procedures may help to raise 'comfort' levels and others have illustrated their role as post hoc rationalisers of decisions (Kerr, 1982; Meyer, 1984). The results of the survey reported above raise further issues specific to the use of formal analysis under conditions of environmental turbulence. For example, how committed are decision makers to rational decision making and how much confidence do they have in the tools and techniques used by decision support professionals ?

The other main contributing factor to organisational flexibility was identified as a particular management style focused on informal information gathering and consensus

decision making. The emphasis on informal information gathering and personal contacts with other managerial staff is reflective of the management style found in Japan. Nonaka & Johansson (1985) identified face-to-face contact and extensive influence networks as being key components of the Japanese approach to information sharing and decision making. Israeli management practices have previously been formally characterised as promoting flexibility and adaptivity (Mevorach & Ofek, 1988), or exhibiting 'a flair for improvisation' (Lawrence, 1990). Such attributes have also been identified with Japanese management (Johnson & Scholes 1984; Ouchi, 1981) and the efficacy of such a style within an Israeli setting has been highlighted by Sagie et al (1990). A study by Ishida (1986) found that Japanese companies place a high value on human resources, a finding reflected in the survey results reported above. Scanning behaviour is also a source of similarity between the Japanese and Israeli management styles. Figure 5.8 showed that the majority of scanning in those Israeli companies accessed focuses on surveillance activities (trade journals, hearsay) as compared with search activities (own reports, in-house models). Keegan (1983) reports a similar bias in the scanning activities of Japanese organisations. Shneider (1989) attributes this emphasis on broad, reactive scanning activities to conditions where there is a weakened belief in the ability of the organisation to control the environment.

Although no evidence was found during this survey of any direct influence from Japan, it might be instructive, as a piece of further research, to perform a comparative analysis of the determining factors for the evolution of such a management style in each case. With regard to possible sources of the observed management style, attempts to classify Israeli management using attitudinal surveys have had inconclusive results. Ronen & Kraut (1977) placed Israel in a cluster designated 'Anglo' whilst Hofstede (1980) positioned it within a 'Germanic' grouping. A review and integration of work in this field by Ronen & Shenkar (1985) failed to find sufficient evidence for placing Israel in any group and classified it together with Japan in an independent group.

A further core finding of the survey is that the key contributory factors to organisational flexibility are human centred in nature. There is strong evidence from both the questionnaire returns and interviews that management consider the workforce and their own management style to be the central determinants of flexibility.

With regard to the respondents attitude towards uncertainty, there is evidence to suggest a passive acceptance of the inevitability of change. If the data which form Figure 5.7 are disaggregated, 78% of all responses indicated either a low or medium level of change in the variables being focused on. This result suggests that respondents do not consider their operating environment as either having been, or likely to be, particularly turbulent. This is a point at which the concept of perceived environmental turbulence becomes useful. Viewed from a personal perspective, a turbulent environment becomes less uncertain with increased experience. As suggested in Section 2.6.1, an acceptance of uncertainty as an intrinsic element of the future promotes a reduction in associated risk and broadens concepts of utility. Both these phenomena can be identified in the survey reported above.

Differences in the way societies tolerate or avoid uncertainty were identified by Hofstede (1980) and the results from the survey described above can be interpreted within the classification proposed by Schneider (1989). Discussions with both senior business managers and academics in Israel towards the end of the survey process also brought to light a previously unsuspected factor in the ability of Israeli management to cope with volatility. The twin facts that the people of Israel are largely either immigrants themselves or the sons and daughters of immigrants, and that their social history over hundreds of years has been characterised by instability and uncertainty, were put forward as suggesting a cultural dimension to their capacity for coping with volatile environments. Any further explanation for these culturally based factors is beyond the scope of this paper (See Schneider & De Meyer 1991, for an assessment of the impact of cultural determinants upon responses to strategic issues.)

5.6 Summary and conclusions

This chapter has reported the design and execution of a questionnaire and interview based survey of decision makers and decision support professionals in Israel. It was proposed that the turbulence of the operating environment would favour alternative approaches to combating uncertainty and the study was designed to expose sources of concern to management, the nature of extant strategies, and the role of formal analysis in these strategies. The findings of this element of the research programme can be summarised as follows:

1. Sources of perceived turbulence are mostly outside the influence of the organisation and information regarding trends in the operating environment is gleaned from mainly informal sources.
2. Formal decision support techniques have a limited influence on decision making.
3. The determinants of the general approach to handling risk and uncertainty have a significant cultural element.
4. Criteria for decision making under turbulent operating conditions reflect issues of flexibility, consensus and feasibility.
5. The focus of flexibility in such circumstances is on human resources.
6. There is evidence for an altered set of goals associated with strategies which emphasise flexibility, focused on survival.

The research findings confirm that management perceive their organisations to be resilient, and the source of this resilience to be both labour flexibility and a management style focused on informal information gathering and consensus based decision making. Ambiguous information on the role of formal analysis techniques raises issues

pertaining to the confidence of decision makers in decision support methods. A point of note on this issue concerns the paucity of any conscious effort to promote the beneficial aspects of the identified management style, suggesting that Lindblom's (1959) characterisation of organisations 'muddling through' successive change events may be applicable.

The results and conclusions of the survey should be tempered by two additional aspects which serve to put the study's findings in context. Firstly, an approach to planning and control based on flexibility may be characteristic of a survivalist strategy. There was no evidence from the study to suggest that such strategies are in any way optimal with regard to maximising any particular measure of success or value. Indeed, a modified utility set is evident in some sections of Israeli industry, particularly the large conglomerate owned by the Trade Union. movement where jobs are as important a goal as profit..

Secondly, the possibility that the determinants of the management style are cultural makes transference of any desirable elements of the approach problematic. Despite the existence of a body of theory concerning cognitive relativism which may form a starting point for an assessment of the transferability of management styles (Wilson, 1970; Cool & Lengnick-Hall, 1985), some of the broader aspects of the approach are not easily replicated. However, on a positive note, Friesen & Miller (1986) developed a rational model of adaptability as an approach to combating turbulence and found that a strategy of 'generalism' dominated. There may therefore be further scope for developing strategies based on flexibility and adaptivity from a rational standpoint.

Chapters 8 and 9 review the policy and methodological findings of this survey whilst Chapter 10 interpretes the survey output within a broader context of matching wider organisational attributes with analysis techniques selection.

CHAPTER 6

INTRODUCTION TO A STUDY OF OPERATIONAL RESEARCH PRACTITIONERS IN THE U.K.

6.1 Introduction

The discussion presented in Chapter 1, concerning the advantages of undertaking an interdisciplinary approach to the problem of long term technology investment, drew attention to the issue of how modelling is used within the decision making process. This theme was expanded in Section 2.2.1 where the roles of models and modellers were discussed. It was also stated that understanding the way in which planning tools are used is as important as a knowledge of their theoretical content. With respect to the subject matter of the thesis as a whole therefore, the survey reported below constitutes an investigation into a second aspect of planning long term technology infrastructures; the selection and use of modelling techniques and their perceived benefit to the organisation. Figure 6.1 shows the focus of inquiry for Chapters 6 and 7.

Figure 6.1 Focus of investigation for Chapters 6 and 7.



In conjunction with the modelling activities reported in Chapters 3 and 4, the survey of O.R. practitioners will enable a comparison between the limitations of the predict and prepare approach to handling uncertainty, and the attitude of practising modellers to these issues. Accordingly, both this and the following chapter address the issue of practitioner use of modelling techniques. Broadly, the aim of the survey is to generate a description of the attitudes of O.R. practitioners towards their tools and activities. As a complementary piece of work to the modelling activity, the survey of Operational Researchers provides information concerning modeller's perceptions of their tools. In particular, the survey focuses on technique selection, the handling of uncertainty, and the perceived benefits and disbenefits of O.R. for the organisation.

The use of models as part of the decision support process is formalised within commerce and industry by the activities of Operations Researchers and other planning professionals. These organisational actors, working as individuals or more commonly in functional groups, are responsible for applying a range of mathematical, programming and simulation techniques to the problems which face their employers. Consequently they constitute a focus for the rationalisation of the real world within an organisational perspective and provide decision makers and line managers with information derived from a range of modelling activities. Irrespective of the organisation's activities, the modeller's influence on decision making may be very high in relation to their hierarchical position within the firm. The reason for this stems from their role as 'rationalisers' and interpreters of both the organisation's structure and processes, and more importantly, of the relationships between the organisation and the outside world.

This chapter introduces a study carried out amongst modelling practitioners in the UK. The aim of this study was to assess their attitudes to, and beliefs in, the techniques and tools they use. More specifically, the awareness by modellers of the limits of what they can achieve with the tools they have at their disposal is of interest. The results of the survey of Israeli management, presented in the previous chapter, suggested that under turbulent operating conditions formal analysis procedures play a reduced role in decision making. It also found that the key aspects of resilience under turbulent operating conditions lie human centred behavioural phenomena. The assessment of such phenomena traditionally lies in the field of organisational theorists or social scientists rather than in the O.R. / M.S. domain. A second, broad aim of the research activity reported below, is therefore to enquire into the contribution which O.R. practitioners could make to the analysis of these softer planning issues. Anticipation of the problems surrounding the use of a specific set of modelling methods may lead practitioners to investigate alternative approaches. The identification of such options constitutes a third level of investigation for the survey.

After reviewing the background to the study, this chapter discusses the methodologies and techniques used for survey design, questionnaire dissemination and result interpretation. A presentation and discussion of the survey's results is then provided in the subsequent chapter. Supporting information for this survey including questionnaire templates can be found in Appendix 3.

6.2 Background to the study and discussion of survey aims.

Although there have been widespread investigations into the influence of different actor's cognition on aspects of the decision making process (Schwenk, 1984; Steiner & Miner, 1977), the role of modellers as an interface between an organisation's environment and the organisation itself has been largely ignored. The study reported in this and the following chapter applies a questionnaire survey method to this issue in order to ascertain the major features of modeller's attitudes to, and level of belief in, their techniques.

Despite limited evidence to the contrary, the contemporary industrial / economic system has swallowed whole heartedly the rational / logical approach to problem solving. The relevance of this statement concerns the authority and power vested in modellers as executioners of this particular approach to problem solving. The relative importance of different approaches to structuring problems has been widely commented upon (see, for example, Chi et al, 1988). By attempting to capture the characteristics and behaviour of multiple component systems in their models, modellers become the arbiters of the organisation's interface with reality. Furthermore, they formalise the processes and characteristics of the organisation itself (ref. § 2.2).

The techniques utilised by modellers offer a wide array of problem solving algorithms, many of which are best suited to, and in many cases specifically designed for, a narrow set of applications. Their simplification and structuring processes, as discussed in Chapter 2, are therefore often dictated by the technique's assumptions and bounds of relevance. However, technique selection and decisions regarding the scope and detail of the study serve to enhance the measure of influence possessed by modellers over the problem solving process.

In addition to their role as interpreters of the organisation's environment, modellers also contribute guidance to decision making through their reports and the output from their models. Acceptance of their recommendations or findings by decision makers is not automatic. Indeed, there must be a thread of assumptions running through the modelling process concerning the consistency of methodology with problem area.

A limited critique of Operational Research methods and applications has been active for many years within the O.R. community. This debate has focused on both the bounds of O.R. and the relevance of the methodology under varying conditions. Somewhat heated at times, the dialogue has taken place within an environment of rapidly changing technological and theoretical advances. These advances have resulted in the tools available to O.R. practitioners being capable of performing a wide range of tasks at very high speeds and levels of complexity. However, a form of Parkinson's law applies here as new techniques and applications have simply increased in complexity and volume, thereby offsetting any gains made by the increases in efficiency as a result of computerisation.

Although modellers face numerous problems in their daily activities, they remain an influential element of the organisation's planning process. There is therefore some comment to be made concerning modellers' own levels of confidence and belief in the relevance and efficacy of their tools and methods. Assessment of modellers' attitudes in this respect would expose the links between formal model application and the informal levels of credence given to them. Additionally it would provide a source of information relating to any incongruencies within the O.R. community regarding these issues.

As a vehicle for investigating the above discussed themes, a survey of relevant O.R. practitioners was designed and executed with the support of the United Kingdom

Operational Research Society. (See Appendix 3 for a report of how the collaboration was initiated and managed). The key themes of the survey design are as follows.

- 1 The determinants of technique selection for any specific problem.
- 2 Qualifications which may be held about the technique selected.
- 3 The major sources of uncertainty associated with the project.
- 4 Uncertainty resolution in the model.
- 5 Sources of incongruence revealed between model and reality.
- 6 Perceived benefits and drawbacks from the general use of O.R. techniques.

6.3 Survey methodology: Problems of design and data collection

Translating the issues itemised above into a survey framework requires both an assessment of relevant query methods and the design of a structured inquiry system for application to a target population. The explicit support of the Operational Research Society provided a superb opportunity to focus the survey on a distinct and relevant subgroup of their membership. Given the size of this population, an interview based survey was considered both an inefficient utilisation of the opportunity and a time consuming option. A mailed questionnaire survey was therefore selected as the most appropriate method of data collection with regard to both operational and functional considerations.

6.3.1 Selection of a target population.

Having obtained the support of the ORS, the relevance of their membership database required assessment. A total of over 2000 records reflecting both national and regional membership patterns are maintained on the database with a number of sort fields available for determining subgroups. Selecting from amongst this membership list involves applying two criteria which reflect the focus of the study and enables a relevant sub-group of potential respondents to be identified. These criteria comprise the following:

1. Respondents should be current practitioners of O.R. techniques within a commercial / industrial setting, and hold positions in active O.R./M.S. departments.
2. Respondents should be engaged not only in modelling but preferably in technology planning or technology related analyses.

Consequently, the database was sorted by industry specification and job title, and provided a listing of O.R. practitioners with the following distribution.

Table 6.1 Sectoral distribution of O.R. survey target population.

Industrial Sector	No. of Individuals
Electricity Supply.	49
Gas Supply.	86
Water Supply.	10
Rail Network.	9
Steel.	32
Telecommunications.	41
Chemicals.	32
Coal	11
Oil Exploration & Supply	55
Shipping.	7
Aircraft Manufacture & Transport	63
Total	395

6.3.2 Issues of response quality and quantity

Mailed questionnaires suffer from two important problems which the researcher is only partially able to influence; response rate and quality of response. Techniques for overcoming these difficulties have been widely covered in the literature (Linsky, 1965; Spaeth, 1977), the general conclusion being that a number of positive steps can be taken by the researcher to enhance both degree and quality of response. One such technique concerns the maintenance of respondent anonymity (Wildman, 1977; Rosen, 1963; Fuller, 1974). This approach does however lead to an increase in the resource cost of the survey as anonymity reduces the amount of information available from early response sources etc.

Of particular interest in the context of this study is the work of Futrell & Swann (1977) who found that anonymous respondents had a lower item omission rate to sensitive questions. A further consideration in this context concerns the corporate nature of some of the information required. Indeed some respondents abstained from completing the questionnaire on the grounds that the information requested constituted commercially sensitive details which, if accessed by the organisation's rivals would damage the firm's ability to maintain competitive advantage. This in itself is an interesting phenomenon as it suggests that the organisations concerned perceive their methods and techniques as a valuable resource.

Resolving the trade off between the desire to offer anonymity in order to enhance response quality and maintaining some record of which individuals from which industrial sectors had already returned a questionnaire involved two steps. Firstly, the respondents were assured in the covering letter that the information provided would be treated in the strictest confidence and that the published results would not specifically identify any individual or organisation. Secondly, each self addressed reply envelope was marked with a code number (partially derived from the O.R. Society's database coding system) which reflected the industrial sector and personally attributed code number of each respondent. This approach proved generally successful and only one complaint was received concerning the issue of maintaining respondent anonymity.

An additional technique which can be used to enhance both the quantity and quality of data is an undertaking to potential respondents to provide a copy of the survey results. Studies on the provision of survey results to respondents has produced dichotomous findings with some researchers exposing a positive correlation between the offer of such information and the level of response (Dillman, 1978), whilst others have found no benefit over a range of response characteristics (Dommeyer, 1985). In this instance there were external reasons as well as internal ones for seeking to provide respondents with a summary of the results. Promoting a good working relationship with both the O.R. society and the respondents constituted a sufficient reason for suggesting that a summary of the survey's results and findings should be published in one of the O.R. society's journals. This was acceptable to the Society and the intention to publish was relayed to the potential respondents in the covering letter. It was also felt that the intent to publish in an O.R. Society journal would confirm the relationship between the survey and the respondent's professional body, thereby increasing the response rate. Indeed, many of the respondents expressed on the questionnaire form their interest in seeing the published findings of the survey.

6.3.3 Questionnaire design

Each issue itemised in Section 6.2 was formalised into either a single or paired question in the mailed survey sheet. The following provides a brief exposition of each question's intent and role within the research activity. (A template of the questionnaire is provided in Appendix 3).

The opening two questions were designed to achieve three goals. Firstly to provide the respondent with a relatively straightforward introduction to the process of completing the questionnaire. These initial responses required the O.R. practitioner to simply indicate the extent of his / her experience in O.R. and tick off from the list provided, those methods and techniques which he / she has experience of (the listing being derived from the Journal of the Operational Research Society's key word references). Secondly, the information from these questions will be of use to the O.R. Society in providing an indication of where the focus of experience and interest is for practitioners in the field. Thirdly, the responses regarding the use of specific techniques can be used as a control variable to identify possible determinants of bias in subsequent responses.

Questions 3-10 form the backbone of the questionnaire and for this reason it is essential to focus the attention of respondents onto a specific piece of work. This will ensure continuity of comment through questions 3-10 and allow analysis of the response set to be completed without concern for any implicit variations in project type etc. Hence the statement preceding Question 3 requires the respondent to relate subsequent answers to a current or recent project which he or she is involved in.

Question 3 asks for a brief description of the project and serves as a reference for subsequent responses. Questions 4 and 5 seek to expose the determinants of technique selection for the particular project under assessment. This information is intended to highlight any positive reasoning behind technique selection and indicate the level of consideration given to this process. Question 6 is aimed at identifying the perceived boundaries of applicability for the selected technique. Furthermore, responses to this question will serve as an indicator of belief in the techniques suitability or relevance to the problem. In this context, Question 6 is central to this element of the research as it challenges modellers to expound their doubts concerning model validity.

By prompting respondents to identify sources of doubt associated with the project, Question 7 deliberately cultivates an ambivalent interpretation as the required responses need to reflect the respondents broad opinion regarding uncertainty about the project. Responses could therefore relate to the representation or implementation issues or to either technology or human centred aspects of the project. Question 8 compliments Question 7 by asking respondents to state how each source of uncertainty was treated. In combination these two questions address the respondent's perspective on pertinent sources of uncertainty and enable a direct comparison to be made between the origin of uncertainty and both representation and resolution of each element of doubt.

Questions 9 and 10 attempt to expose an element of the relationship between the modelling activity and decision making by asking respondents to identify areas where the models they used were incongruent with reality. An important feature of these questions is the focus on both internal (to the organisation) and external sources of variance. The response set should consequently contain information regarding controllable and non-controllable sources of incongruence. - It should be noted at this point that grammatically Question 9 is badly worded; a fact which partially explains the low response rate to this particular question (see Section 7.2).

Following the standard question format which was used in questions 1-10 (i.e. interrogatory), the last two elements of the questionnaire adopt a statement completion framework. Statements 1 and 2 prompt the respondent to comment on the advantages and disadvantages to the organisation from employing O.R. techniques. This response set will provide information about the perceived utility of O.R. from the point of view of the practitioners themselves.

In order to facilitate and encourage the volunteering of additional information on any aspect of the issues raised, a blank sheet was provided at the rear of the questionnaire and respondents prompted to use it as a comment / suggestion page. This element of the

response set proved highly productive and generated enough information to enable an unstructured but formal analysis of its contents to be undertaken.

A covering sheet for the questionnaire provided a point of contact for any queries and encouraged respondents to complete the questionnaire in an uninterrupted period of time. A total of 380 questionnaires were initially distributed which, after a 6 week period, were followed up by 312 reminder letters (15 of the original target group had overseas addresses and were not included in the survey). Overall 30% of those individuals sent a questionnaire replied in some form (either by letter, phone, or by returning a completed form), and 23% of the total population provided a completed, useful response. This final figure is encouraging as a response rate for a postal questionnaire but somewhat low given the explicit support of the target population's own professional institute.

Piloting of early versions of the survey text took place within Cranfield Institute amongst MBA students with an O.R., Project Management or other related background. A copy of the final version, together with the covering letter signed by the general manager of the O.R. Society can be found in Appendix 3.

The quality of responses was patchy with some respondents failing to complete the whole questionnaire. The major factor behind both the failure to respond at all and the failure to fully complete the questionnaire appears to be a paucity of practitioners. The vast majority of comments which accompanied non-completed forms mentioned the fact that the respondents were no longer directly involved in Operational Research activities. Extrapolating the figures, it would appear that over 20% of the Society's membership are not currently in positions which require knowledge or the application of O.R. methods and techniques. Appendix 3 provides information concerning the characteristics of the response population together with details about the number of responses from each industry sector and the range of experience represented by the response group.

6.4 Data Analysis Methodology

Qualitative research is a relatively new branch of social analysis and relies upon the questioning and interpreting skills of the researcher rather than formal technique and analysis skills (Robson, 1986). An important element of this type of research concerns the data analysis stage. The definition of a set of research questions has been identified as preventing the phenomenon of 'data dredging' (Alt & Brighton, 1981), and this warning is particularly relevant to research programmes where relationships between various elements of the response set are the focus of study. Coding the responses numerically and applying statistical tests to them in a search for significant levels of relatedness will inevitably lead to the generation of a data set which lends itself to additional numerical analysis thereby allowing a multitude of combinatorial results to be assessed. By analysing the response set by categorising each response and restricting interpretation to comments about the distribution and characteristics of the original response set, the problem of data dredging is overcome. Essentially, the original data

never loses its format and is therefore never available for assessment in an abstract form. The method described above is linked to both content analysis and cluster analysis. It also has elements of a number of other qualitative analysis methodologies such as cognitive mapping. Such an agglomeration of techniques should not be interpreted as a marriage of convenience, the determinant of technique selection is reflective of the type of data received, the type of questions asked, and the format of interpretation required.

Formal techniques for analysing qualitative, text based data are lacking (Tuck, 1976; May, 1978) and there have been various attempts to develop novel approaches to such forms of assessment (Jones, 1981). Whilst the raw data generated by the survey under consideration were of a qualitative and often complex nature, many of the problems of interpretation and analysis are overcome by maintaining a simplified question structure. In addition, the pilot survey process enabled many ambiguous and contradictory elements to be eliminated from the questionnaire's language, making the responses from the final survey more closely bounded.

Two types of analysis technique were utilised for assessment of the questionnaire returns received from the O.R. Society practitioners. A small subset of the collated data lends itself to some form of statistical analysis. Simple frequency distributions and mean values were applied in these instances. The remaining data was in a textual format, the responses being typically multi worded replies concerning the practitioner's use of O.R. techniques. Analysis of this second data type was achieved by the use of a variant of the Content Analysis methodology discussed below.

Content Analysis as a social science data assessment tool has its roots in studies aimed at determining the relationships between various media approaches to subject areas. In the 1930s these methods were adapted and used in a number of social science contexts (see for example Laswell, 1938). Further developments of the methodology followed (reviewed in Berelson, 1952) and the term is today applied to a range of data analysis techniques, all of which possess two common features. Firstly, its data consists of verbal, written or other symbols which make up the content of the communication. Secondly, its procedures aim to be exact and repeatable, and seek to eliminate any bias which might result from the judgements of a single investigator. Content analysis thereby employs an explicit, structured activity sequence for assembling data, classifying or quantifying them to measure the concepts under study, and examining their patterns / relationships. Interpretation of any findings can then be carried out with a precise and empirically robust basis of data analysis.

A major problem with using content analysis effectively is the selection of units of analysis. According to Berelson (1954), five major units of analysis are identifiable; words, themes, characters, items, and space-time measures. The unit selected for the study reported here was that of theme. Although these are sometimes complex and perhaps unreliable under some conditions (Kerlinger, 1973), the context within which the interpretation of results takes place generally allays any related fears regarding accuracy or robustness.

Whilst being a general framework for text based data analysis, Content Analysis provides some measure of orthodoxy for the methodology used to assess the O.R. practitioner questionnaires as described in more detail below. It would be both unreasonable and ill advised to adopt unreservedly and wholly, a previously used adaptation of the content analysis method for use here. A greater degree of relevance and usefulness can be achieved by conforming to the general principles and adapting the details of classification and interpretation to suit the format and characteristics of the response set.

Accordingly the technique described below, whilst being simple to execute is robust with relation to the data type and format, and allows a high level of confidence in the results. Analysis of the textual data was therefore conducted as follows: Each question response set was allocated a series of categories reflecting the range of characteristics contained in the replies. These categories were then confirmed by asking a detached second party (with knowledge of the appropriate terminology being used), to suggest a relevant classification framework based on the focus of the question and the objectives of the questionnaire. A sorting process was then executed to provide a distribution of the responses amongst the categories. As with the category formulation, the allocation procedure was repeated by several individuals, providing some level of reliability for the results.

6.5 Summary and conclusions

Chapter 6 has provided the background to and details of a survey carried out amongst O.R. practitioners in the UK. The broad aim of the study is to assess the attitudes and beliefs of modellers concerning the tools and techniques they utilise. Questionnaire formulation and design have been discussed in the context of both the broad aims of the study and the nature of the response group. In addition, an outline of the data analysis methodology used to interpret the derived data set has been presented.

It has been shown that there are no 'off the peg' frameworks or techniques available for assessing the type of data contained in the questionnaire returns and a variant of Content Analysis has been developed and defended as a relevant tool for data analysis.

CHAPTER 7

ASSESSING THE PERSPECTIVE OF OPERATIONAL RESEARCH PRACTITIONERS ON THEIR ROLE AND APPLIED TECHNIQUES

7.1 Introduction

The previous chapter outlined the functional and operational details of a questionnaire based survey of OR practitioners. Chapter 7 is intended to present both the results of this survey and a discussion of them in the context of the issues outlined in Section 6.2. Throughout this chapter the focus is on the behavioural elements of modelling in general. It should be remembered however that the response group has been selected on the basis of industry type and job specification and it is therefore reasonable to assume that they are representative of the modellers alluded to in Chapter 1. Essentially this means that they are involved in technology planning in its widest form.

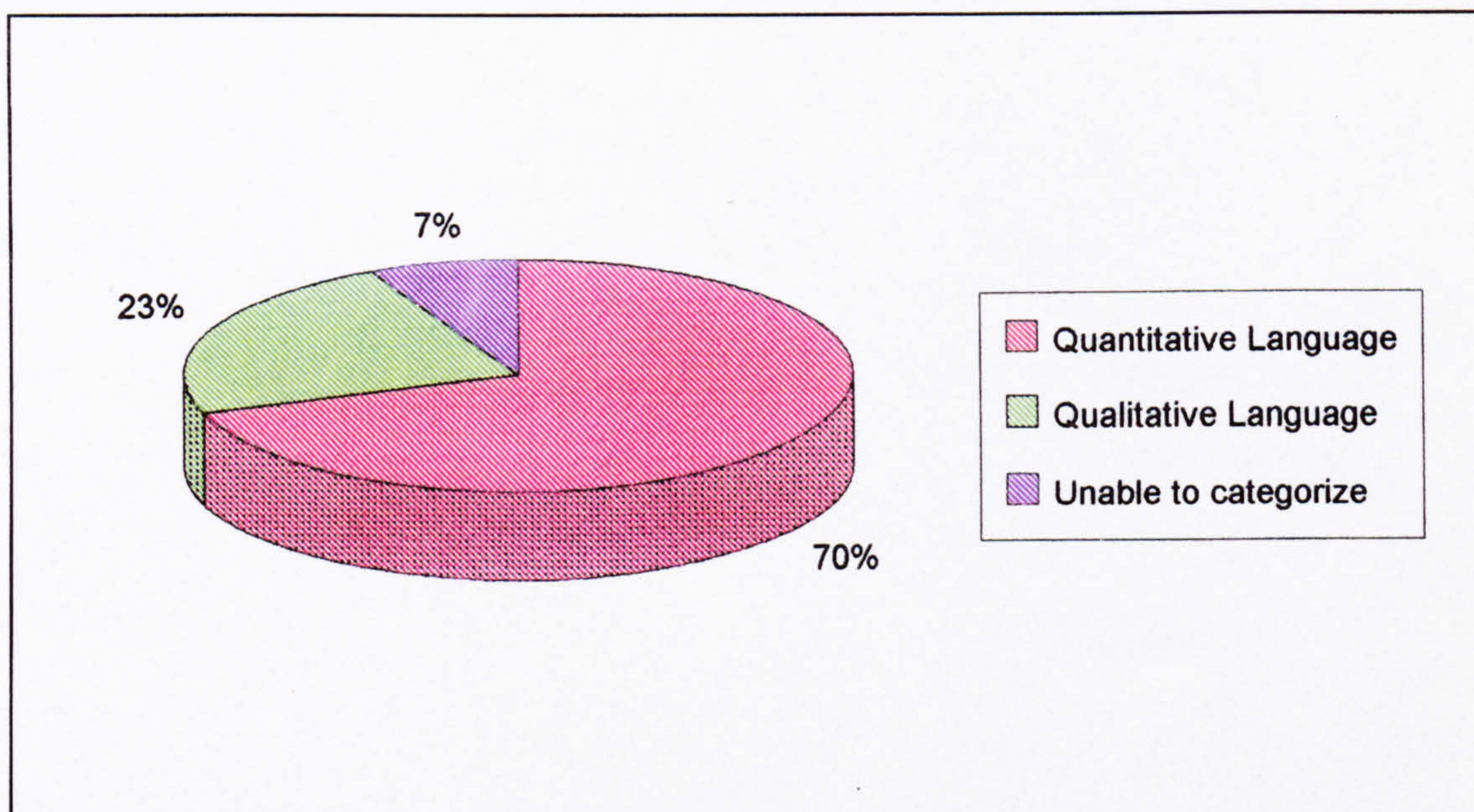
As mentioned in the previous chapter, very little work appears to have been carried out on the attitudes of modellers in this context. Whilst the effect of decision making styles (Cowan, 1991; Brightman et al 1988) on model use and the effectiveness of OR techniques on organisational activities (Lonnstedt, 1973; Goslar et al, 1986), has received attention, the precise role and influence of modellers as formal constructors of the organisation's reality is a subject which has been largely ignored. The following study therefore represents a relatively novel departure in this field by emphasising the importance of modellers as architects of the organisation's interface with reality.

7.2 Results of the survey of Operational Research practitioners.

As discussed in Section 6.2, the selection of a relevant technique for problem analysis is one of the influences which modellers hold over the organisation's activities. The choice of a tool amongst those available or known is restricted by both the type of problem being addressed and the skills available to the project team. Possession by the organisation of a relevant and comprehensive knowledge base (as possessed by employees) is therefore of central importance to the ability of the organisation to utilise available techniques. Identification of an appropriate technique would, if rational processes were dominant, follow similar patterns, irrespective of application. Rationality however is both contextual and relative, and often involves an assessment of trade offs between competing criteria. Hence the reasoning behind the adoption of a specific technique will reflect a variety of concerns, dominance by any one being determined as much by the limitations of the modeller as by the needs of the customer. A comprehensive discussion of these issues can be found in Rosenhead (1989) where examples of several problem structuring approaches are provided.

The technique used will also have some relation to the way in which the problem has been formulated. This is neither a straightforward nor a simple task, as problems are often perceived in different ways by different individuals or groups of individuals resulting in a need for interpretation and synthesis. Within the organisational structure however, modellers normally receive the problem in a well defined format (how this is arrived at would constitute a further interesting study), and the selection of a relevant technique is independent of wider problem contexts. A particular point of interest here is that problem definition at the modelling stage is couched in terms which lend themselves to quantitative interpretation. Responses to Question 2 which prompted the respondent to describe a recent project were strongly biased towards language which included quantitative elements rather than qualitative or neutral words and phrases (Figure 7.1). There is no correlating evidence to suggest whether problems are actually handed down from senior management in such a form or whether it is interpreted by the OR practitioners in this way. It is clear however that the respondents perceive their role as essentially one of providing quantitative solutions to quantitative problems. The two categories of response which did not fall within this grouping concerned customer service levels and the development of a model to assess inter-departmental consistency in technique application.

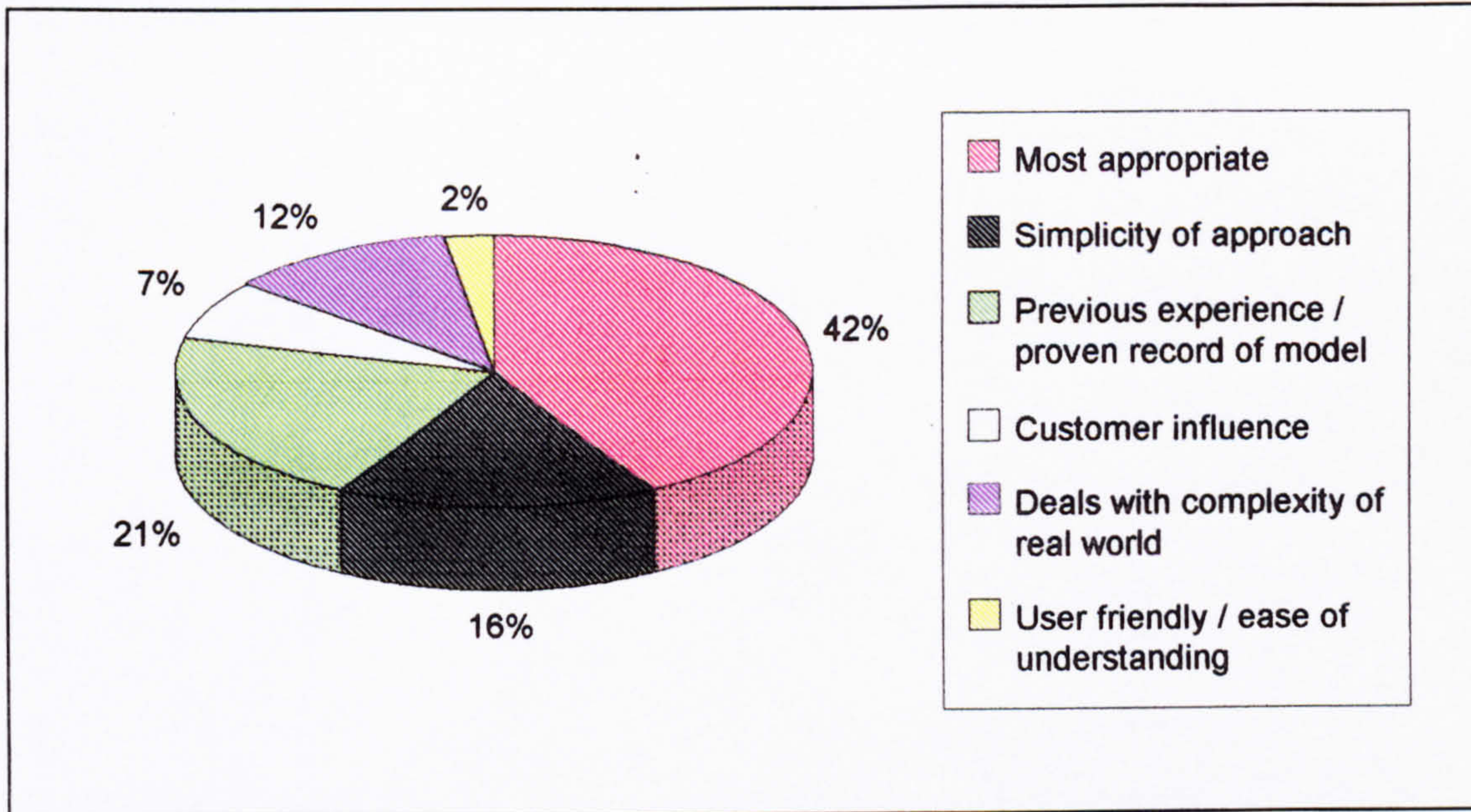
Figure 7.1 Bias of language used to describe a recent project.



As a justification for using the selected technique, six major categories of response were proffered (Figure 7.2), each of which represents one criteria of the range mentioned above in relation to technique selection. None of the respondents alluded to any process being used to formally analyse the options available although several intimated that "detailed consultations" had taken place before a technique was finally adopted. A further omission from the response set involved the paucity of any reference back to the problem formulation which confronts the modeller. The only response type which could

be identified as reflecting this concern consisted of a sub set of those who stated that the chosen tool was the "most appropriate".

Figure 7.2 Justification for using selected O.R. technique.



This category of response ("most appropriate" or "best available"), covers a range of comments which were interpreted by those involved in the analysis as reflecting a neutral attitude by respondents towards the adoption of a selected technique. Although this response group was by far the most common in this instance, it is difficult to draw any concrete messages from its prevalence other than to note that the respondents did not tax themselves in composing a reply !

The two major positive issues which are identifiable in determining selection of analysis techniques pertain to the issues of understanding and experience. Responses grouped in the understanding category focused on the need to make either the analysis process or its output comprehensible and perspicuous. "User friendly" and "effective communication" are common terms in this response group, emphasising a desire to make the analysis as relevant as possible to utilisation as a decision making tool in a wider context as opposed to a solution generator. This issue of producing analyses which enhance the ability of decision makers to explore the relevant decision space was covered elsewhere in this text These survey results provide an indication that such considerations are high on the agenda of OR practitioners. Those responses grouped under the 'customer control' category may also be considered as reflecting a desire to maintain a link between technique selection and wider decision making considerations, particularly those which are client driven.

The experiential category depicted in Figure 7.2 contained responses centred on issues of 'conventionality' and 'proven record'. This reflects a desire to maintain an acceptable level of performance as derived from earlier achievements with the method. This

response group can be interpreted as a sub set of the 'best one for the job' category as it infers a lack of scanning on behalf of the practitioner for either an alternative or a more fundamental justification for technique adoption. Alternatively, it may be a reflection of either the consistently successful implementation of a particular technique in a particular setting or reflect a conservative approach to the use of such techniques.

The final feature of the response set shown in Figure 7.2 concerns the ambivalent inferences provided by those categories which indicate selection on the grounds of simplicity and those which indicate selection on the grounds of complexity. Further consideration of these two categories exposes some interesting facets of the OR activity. The first characteristic to note is that there is no obvious distinction between the types of technique being commented on. In particular, simulation techniques are mentioned more than once in both categories. Hence, technique selection does not appear to be related to the relative simplicity or complexity of any particular method. Secondly, and more significantly, when the responses for each category are considered in more detail a link back to problem formulation is exposed which indicates a desire to balance three distinct factors. Responses in the 'simplicity of approach' category included the following typical comments against the use of more sophisticated and involved techniques:

- Use of more complex methods does not result in a substantial increase in accuracy (A comment supported by the findings of the modelling activity reported in Chapter 4).
- Problems associated with describing complex models to senior management.
- Data quality not of sufficient quality.
- Time and resource constraints.
- Scope of the project limited.

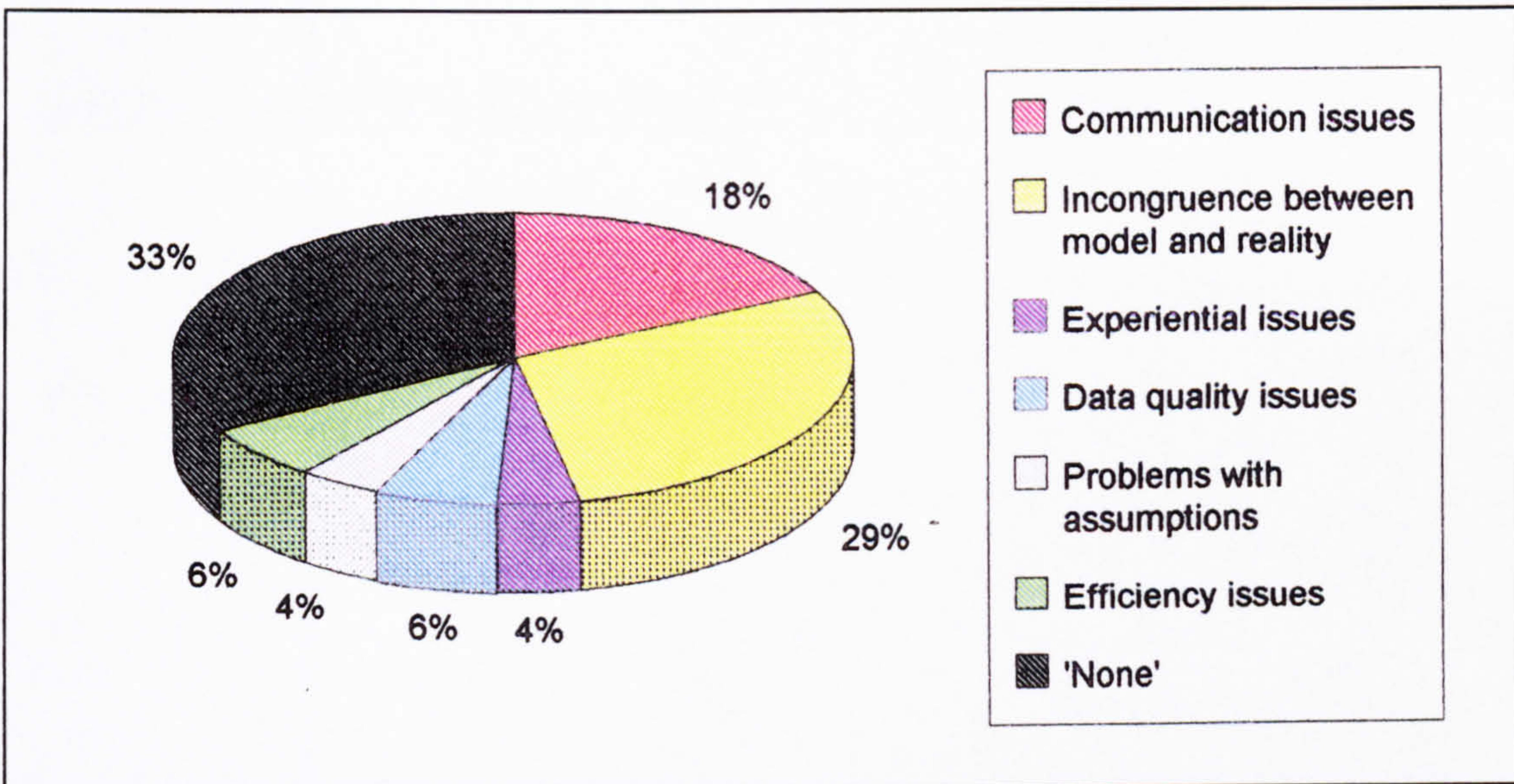
Conversely, none of the responses categorised under the heading relating to a desire to capture complexity made any effort to justify their decision *not* to use a simpler technique.

This finding suggests that OR practitioners are well aware of the limitations of their tools and act to provide explanations of model bounds in situations where large degrees of simplification are evident. Specifically, the common forms of such bounds comprise wider corporate criteria such as efficiency constraints and restrictions in problem formulation and communication of results. All these considerations will, of course be relative, and this is witnessed by one response which cited the complexity of the model as a crucial selling point to the eventual client.

Finally with relation to this issue, if both the 'simple' and 'complex' categories are unified, a majority of respondents commented on some sort of trade off between different levels of complexity as constituting one element of technique selection.

Evidence concerning the level of confidence in particular techniques is shown in Figure 7.3.

Figure 7.3 Reservations held regarding the use of the selected technique. (Percentage of total responses in each category).



Over 30% of respondents positively stated that they had no reservations about using the chosen technique for the project under consideration. This provides an indication as to the level of conviction held by OR practitioners regarding the relevance of the tools they utilise. In detail, 92% of those replies which indicated no reservations were an unambiguous 'None', a fact which can only be interpreted as indicating unconditional faith in the technique's relevance and use. No discernible bias in the type of technique referred to is evident in these responses and they range in character from Risk Analysis and Simulation to Queuing Theory and Linear Programming.

The other major grouping of responses to this question comprises those who positively identified sources of incongruence between the models they were working with and the system being modelled. The origins of incongruence themselves ranged from future uncertainties to scale effects. By far the largest subset within this response category however identified 'soft' or 'human' components of the real world as being difficult to represent. The range of techniques represented by these responses is similar to that contained in the responses which identified no reservations, and there does not appear to be any sectoral or experiential bias in either set.

Finally with reference to this question, there is some support indicated for the proposition made in relation to the responses to question 5 concerning communication of results. The only other significant response category was that containing responses centred on the ability of the technique to be communicated to either the user or other developers. Indeed, with regard to the response set as a whole, concern about the communication of ideas, concepts and results begins to take on a pre-eminence.

Responses to the questions concerning sources of uncertainty associated with the project under consideration and means for addressing this uncertainty were of inconsistent

quality; many respondents choosing to not answer these questions at all. For this reason, the data set can only be tentatively analysed. The grouping procedures which characterise the data analysis technique were found to be an ineffective method of clustering responses in this instance. In order to gain an identifiable distinction between responses it was necessary to determine broad categories for answers to Question 7 and allow those involved in the classification process to sort the responses to Question 8 as sub-groups. Figures 7.4 and 7.5 illustrate the main features of this data set. (N.B. each respondent was able to list more than one answer to both questions).

Figure 7.4 Techniques for dealing with sources of doubt. (Sub-set relating to accuracy of data being major source of uncertainty).

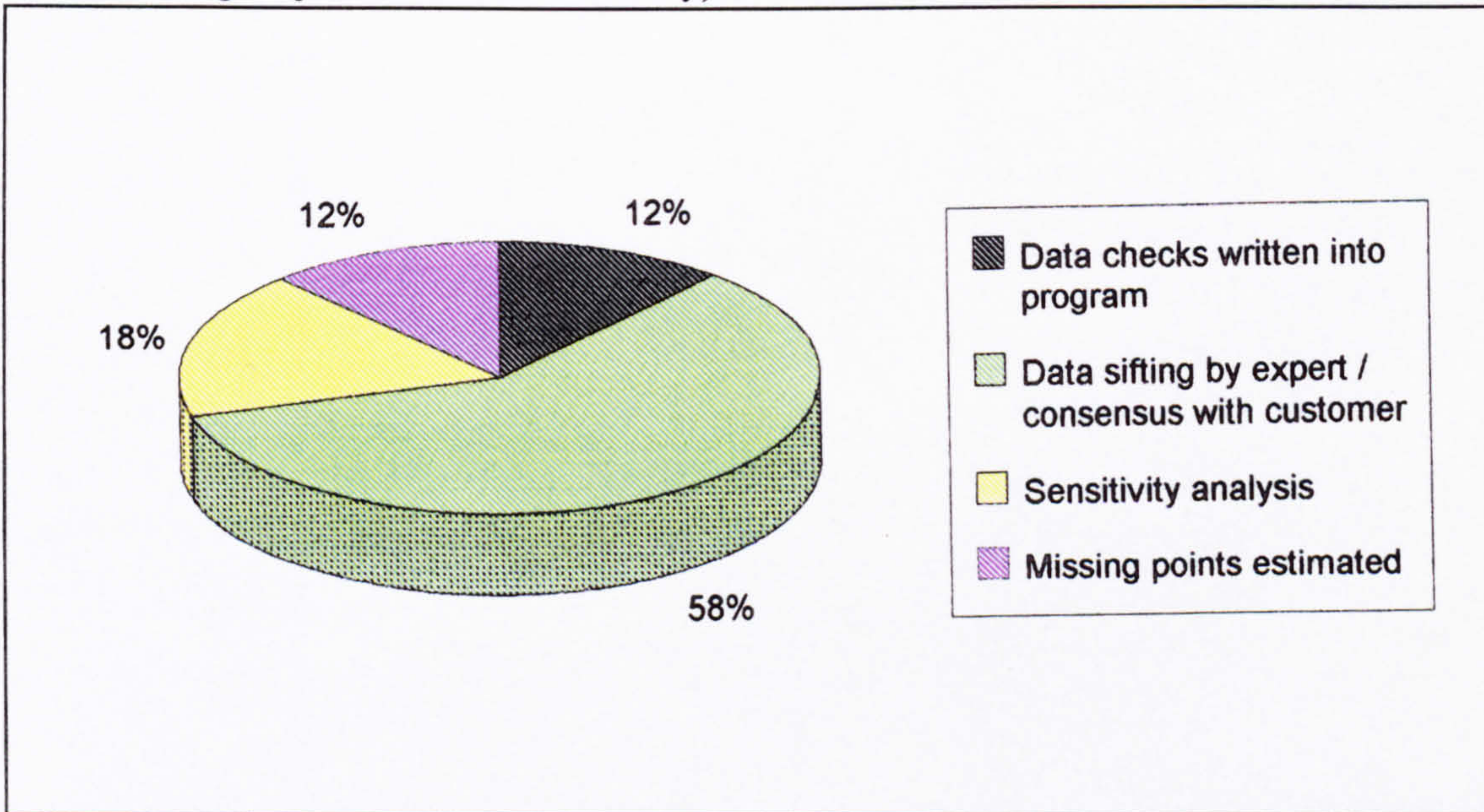
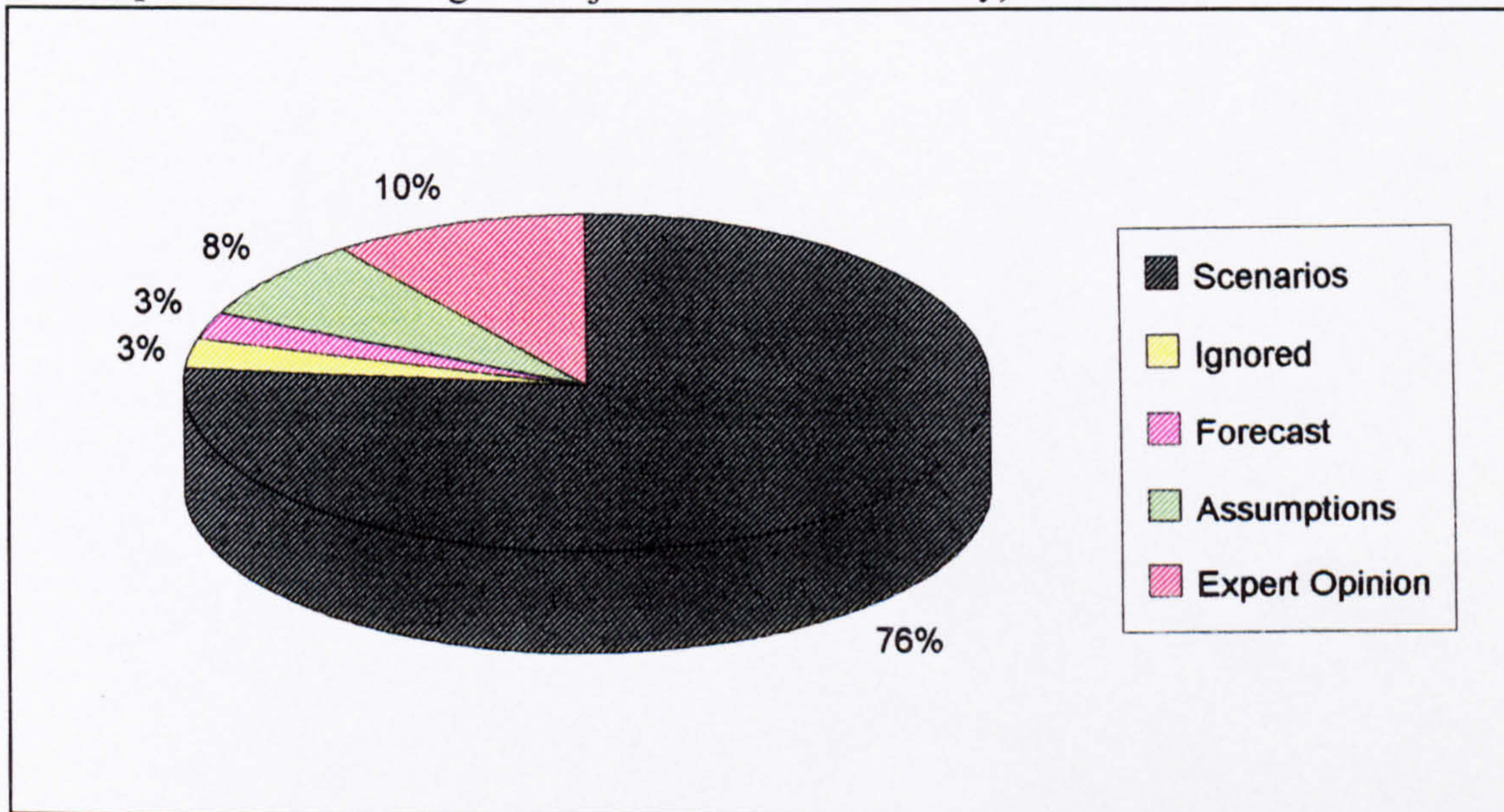


Figure 7.5 Techniques for dealing with sources of doubt. (Sub-set relating to changes in model parameters as being the major source of uncertainty).



The first point of interest regarding the response sets depicted in Figures 7.4 and 7.5 concerns the initial classification of responses to Question 7. Doubts relating to either the accuracy of current data or the possibility of future data / boundary conditions changing, constituted 72% of all responses to this question. The split in the responses between the two sources of uncertainty was almost equal; one set being biased by several dense responses (i.e. multiple answers to a single question.)

Figure 7.4 shows that doubts regarding the accuracy of data used in the model were mainly addressed by variants of Delphi type techniques. These involve a process of consultation with either an expert or the customer in order to provide a consensus on data values. Sensitivity analysis, estimation and weighting techniques were also used but not to the same extent as the consultative procedures. Methods for dealing with uncertainty regarding the future state of model variables or boundary conditions (Figure 7.5) focus strongly on the use of scenarios with alternative methods including the use of expert opinion and assuming accuracy.

Interpreting these results is difficult due to the fragility of the data set (see above). However, it is clear that scenario generation constitutes the major option for uncertainty resolution in the cases surveyed.

Mention was made in Section 6.3.3 of the badly presented phrasing of Question 9. This unfortunately resulted in the response rate to this particular query being very low. Several comments were made by respondents concerning this question, the majority of which concerned the meaning of the term 'operationalization'. The use of this term, combined with the length of the question appears to have created a barrier to understanding. Phrasing ideas and concepts in a way which is comprehensible to a target audience is a key component of successful survey technique. In this example however, the phenomenon of 'group speak' is evident as the term which caused difficulties is widely used and understood within the author's own academic environment. This probably also explains why the potential for confusion was not identified during piloting. (The pilot group consisted of Cranfield MBA students in their final term.)

The activities of OR practitioner have an obvious influence on the behaviour and development of an organisation. Analogous to the perceived worth of OR techniques as valid problem solving algorithms, there will be a perception of the value of the techniques within an organisational setting. From the modeller's perspective these benefits or disadvantages will reflect levels of belief in the worth of the techniques themselves in a wider context. (Although it should be noted that O.R. practitioners are often unaware of the extent to which other elements of the decision making process serve to enhance or denigrate their own input). Nevertheless, it is instructive to assess the perceived contribution of OR techniques from the stand-point of OR practitioners if only to expose confidence levels and any incongruencies between industry sectors etc.

The range of responses collated from answers to the question of what are the advantages to the organisation from employing OR techniques, is impressively diverse (Table 7.1). Out of a total of 64 relevant questionnaire sheets, 148 replies were analysed (each

respondent was able to list more than one advantage if so desired). From these replies 17 categories of response were identified. These responses provide an indication of the breadth and variety of positive benefits as identified by OR practitioners. (Key words or phrases used during categorisation are highlighted with quote marks).

Table 7.1 Identified advantages to the organisation from the use of Operational Research Techniques.

IDENTIFIED ADVANTAGE	% OF COMMENTS FOCUSED ON THIS ISSUE
Provides a broader 'understanding' of often 'complex' problems	13
Develops a 'scientific' approach based on 'quantification'	11
Allows a 'structured' approach to problem analysis	10
Constitutes an 'independent' / 'objective' analysis	10
Resultant decisions made / seen to be made on a 'rational' basis	9
Ensures 'cost effective' decisions / 'effective' resource allocation	9
Results in 'better' decisions	6
Provides a 'rational' basis for decision making	5
Miscellaneous organisational considerations	5
Allows 'scenarios' to be considered	4
Provides a 'logical' approach to decision making	4
Expands the 'range' of 'alternative solutions'	4
Improves 'communication' within the decision making process	3
Provides an 'analytical' approach	3
Enables 'monitoring' of processes	2
Engenders 'competitive advantage'	1
Allows 'accountability' to be maintained	1

The major bias of the response set presented in Table 7.1 concerns the assumptions made concerning a correlation between the application of formal reasoning structures and some benefit to the organisation. If those categories which include a reference to such a link are combined, over 50% of comments made fall within the relevant classification. This broadly supported response group suggests that there is a widespread conviction (at least publicly) that the rational / objective problem solving approach

exhibits desirable characteristics in relation to planning. If the four major contributing categories to this broad conclusion are taken as representative of the response set (they actually constitute 44% of all comments and 72% of all respondents), a partial representation of OR practitioner beliefs in their activities begins to emerge.

It is clear from the results presented in Table 7.1 that the OR practitioners accessed broadly consider themselves as the calculating arm of both functional and strategic management planning operations. As service providers however, they perceive their contribution as being much wider than mere number crunchers or programmers. The emphasis in much of the OR literature on careful problem formulation and co-operation between analyst and client provides a reference for this broader perception of function within the organisation.

Much of what has been inferred above regarding the OR practitioner's perception of both his own and his techniques' roles in the organisation are supported by the responses shown below in Table 7.2 This is generated from responses which indicated what disadvantages could be identified for the organisation resulting from the use of OR techniques.

Table 7.2 Identified disadvantages to the organisation from the use of Operational Research techniques.

IDENTIFIED DISADVANTAGE	% OF COMMENTS FOCUSED ON THIS ISSUE
'Misuse' / erroneous 'interpretation' of results	34
Mismatch between 'technique' and 'problem'	10
Ignores 'soft' / 'behavioural' issues	9
Used as a 'substitute' for 'common sense'.	8
Engenders 'Analysis Paralysis'	8
'Time' consuming process	7
Problem not appreciated or 'understood' by analyst	6
'Costly' process	6
Solutions are 'technology' / 'technique' driven rather than 'problem' driven	4
'Oversimplification' of problem	4
Over emphasis on 'theoretical solution	3
Over emphasis on 'rationality'	2
'Not suited' to present day business problems	1

The major cause of concern for respondents in the context of OR technique disadvantages is focused on the process of result interpretation and application. There is obviously a very strong feeling that the output from OR techniques is prone to misuse. The main reasons for such misuse involve unsubstantiated assumptions about parameter measures and the inappropriate use of output. This finding is enhanced by the comments on the lack of any soft or behavioural perspective on the study and the mismatch between technique and problem are pertinent in this context.

In order to expand the representation of OR practitioners presented above it is possible to include two further characteristics. Firstly, the respondents are keen to identify the limitations of their tools and provide as much information as possible concerning the contextual relevance of the output. Secondly, there is an appreciation of the planning process which goes beyond their role as modellers or analysts.

On the last page of the practitioner questionnaire a space was provided in which respondents were invited to comment generally on their experience of the use of OR techniques. The following discussion is based on an analysis of the 28 individuals who contributed to the study in this way.

The overwhelming impression given by the comments provided concern the emphasis given to OR as an approach rather than as a set of techniques. More specifically, the human centred characteristics or 'way of thinking' engendered by an OR background are emphasised as being of greater benefit to the organisation than knowledge of formal analysis techniques. Indeed some respondents expressed reservations about tackling a questionnaire which expressly adopted a technique based typology of the profession.

In a similar vein to this lack of formality were several comments to the effect that pre-defined techniques are rarely, if ever, utilised without modification and adaptation to provide a contextual setting. Other issues raised included:

- The important role played by inter-personal skills in OR activities.
- The need to ensure a comprehensive understanding of the problem.
- A positive, if somewhat qualified attitude to the emerging 'soft' techniques.
- The problem of winning over senior managers before new techniques can be adopted.
- The important role played by 'common sense'.

This final issue is representative of a somewhat perplexing conundrum which emerges from the study as a whole. Despite the exhibited emphasis on the importance of 'rational' and 'structured' approaches and 'analytical' / 'scientific' processes, there are widespread references to 'common sense'. It is unclear just what kind of skill or knowledge is being referred to with this term but the context it is typically used in suggests that it refers to decision makers rather than of OR practitioners. Overall some 34% of respondents alluded to common sense being under threat from over complicated analyses.

7.3 The perspective of Operational Research practitioners towards their role and the appropriate use of their models.

Two main themes can be isolated from the questionnaire responses detailed above. Firstly, there is an obvious concern on behalf of O.R. practitioners about the correct use and interpretation of their techniques and resultant output. Secondly, respondents emphasise the importance of O.R. as an approach, specifically a rational / scientific / logical approach. The following two subsections take these issues and discuss them in greater detail drawing on evidence from the survey.

7.3.1 Bounding the use of Operational Research techniques and model output interpretation.

The study reported above clearly shows that OR practitioners are both aware of, and concerned about, the way in which the models they develop are utilised by decision makers. Specifically, they are keen to ensure that details concerning assumptions, data sources, boundary conditions, and limits to application are communicated. In many instances, the language used in the responses emphasises a need to detail the *failings* of developed models so as to draw attention to their relevant scope of application. This illustrates a pragmatic element to the OR practitioner's attitude to his / her role. In recognising the bounds of the analysis they are responsible for, OR practitioners both implicitly demonstrate an understanding of the limitations of their modelling activities, and exhibit an appreciation of the importance of effective communication. This latter trait can be seen as a direct attempt to close the 'gap' in mutual understanding between decision makers and decision support staff identified by, amongst others, McArthur (1980).

However, the responses to Question 6 (Figure 7.3) indicate that this view of modellers cannot be unreservedly accepted as a significant minority of respondents were unwilling to state any doubts they had about adopting a specific technique. It is possible that converse features of OR practitioner's behavioural characteristics have been exposed and that there are contextual determinants of the responses which have not been isolated.

Looking at the broader results presented in Figure 7.3 there emerges a pattern where approximately one third of respondents identify incongruence between reality and model as a reservation for technique adoption and about one third who positively state no reservations. (Further disaggregation of the data suggests that this is a consistent trend across variances in technique, industry sector, and type of project). Interpretation of these results need not be within a dialectic framework as there is nothing essentially contradictory in them. What they do suggest however, is that there are conditions under which OR practitioners are able to articulate some measure of critique of the techniques they utilise. Identification and examination of these conditions is not possible within the confines of this study. It would be illuminating however to develop this research area further and test some general hypotheses concerning the determinants of either an ability

or willingness to doubt the relevance of specific techniques.

Despite the possibility that there may be a conflict of interest in expressing levels of belief in adopted models, the broad finding with regard to modeller's attitudes to the use of their models is that they appreciate the pragmatic aspects of translating models into action and act to facilitate communication of the associated problems. Supporting evidence for this can be found in the free text responses collected at the back of the questionnaire. Many of these stated that rarely, if ever, were techniques used 'off the shelf' (see above). By engaging in information promotion, OR practitioners are counteracting the 'political cleavage' identified by Astley et al (1982) as representing the multiple interests which individuals may be pursuing during the decision making process.

Previous research into this area has produced results which help to interpret the findings. As mentioned in the previous chapter, Quinn (1980) suggested that formal analysis procedures may help to raise 'comfort' levels. Of more significance to this study, and as mentioned in Chapter 5, Edelman (1985) and Feldman & March (1981) found strong evidence for the symbolic use of language and information to convey rationality and thereby legitimise organisational actions.

The survey outlined above however has a greater level of affinity with Langley's comprehensive study which focused on why formal analysis techniques are used. In her final comments she states that:

"In its use for communication, direction and control, and symbolic purposes, formal analysis acts as a kind of glue within the social interactive processes of generating organisational commitment and ensuring action. Organisations that undertake a great deal of formal analysis may not necessarily be more rational - but they are likely to be more pluralistic." (Langley 1989).

7.3.2 The influence of the rational / scientific approach to problem solving. An Operational Research practitioner perspective.

Beliefs regarding the relevance and benefit of a specific methodology can provide an indication of perspective by outlining a framework described by stated opinions. The open ended nature of the statement completion queries provides a subject specific but structurally unbiased vehicle for collecting such information. As outlined in Section 7.2 a keyword analysis of these statements has been carried out and used to generate Tables 7.1 and 7.2. Although a level of abstraction is required to relate stated opinions to perspective, the method is sufficiently similar to the cognitive mapping approach proposed by Eden et al (1983), and sufficiently robust as a statistical analysis, to allow some measure of confidence in its results.

Overall, the results from these two tables suggest that whilst OR practitioners can be broadly characterised as adherents of a rational/scientific approach, they recognise their inability to faithfully represent the target system's complexity or detail. Consequently, they are concerned to communicate these failings to other actors in the decision making process. Speculating as to the reasons for the dominance of such an approach is beyond the scope of this work. It should be noted however that there was little evidence to indicate the use of any of the alternative formal methods which are available to OR practitioners. (Examples of such alternatives include those suggested by Rosenhead (1980), Friend & Hickling (1987), and Eden et al (1983)). Furthermore, the OR movement is rooted in the belief that by applying science to management problems, some enhancement of control and performance can be achieved. This methodological basis is reflected in the comments concerning the role of O.R. as an 'approach' as opposed to a 'toolkit'. In order for any of the alternative methodologies and techniques mentioned above to become accepted, it may be necessary to broaden the 'approach' to include previously externalised elements of the problem. Consequently, it may require an expansion of what is meant by 'rationality' or 'scientific' before such change is possible. Specifically, the emphasis placed on human characteristics as sources of flexibility identified in Chapter 5 would suggest that behavioural issues (often highly irrational), are important elements of survival strategies.

Evidence for the influence of a dominant approach to problem solving based on 'rationality' has been identified by both DiMaggio & Powell (1983) and Zucker (1987). Other institutional theorists make the point that organisations would promote the aura of rationality as a legitimate framework for decision making as external sources of support would treat anything else with suspicion. The findings reported above sustain the view that rationality is a key feature of modellers' perceptions of formal analysis techniques but also point to a widespread concern with communicating the limitations of the rational approach. As mentioned earlier, this survey is one of the few which has positively sought OR practitioners' views on the use of their techniques within a decision support framework. Integrating the survey's findings with previous studies of decision maker attitudes creates an agenda for combined studies of the relationships between the two. Such an agenda should address primarily the question of incongruencies of perspective, attitude and belief within formal decision analysis procedures.

7.4 Summary and conclusions

Following on from the survey setting and methodology presented in the previous chapter, Chapter 7 has provided a detailed examination of the survey's results and developed a discussion of its pertinent aspects. Four broad conclusions pertaining to the attitudes of OR practitioners can be gleaned from the survey. (Numbers in parentheses represent survey questions and statements which provide supporting evidence)

1. OR practitioners are cognisant of the limitations of the tools they use.
(Q5,Q6,Q7,S2,Comments)

2. OR practitioners are concerned to communicate these limitations to other actors in the decision making process. (Q6,S2)
3. A belief in the 'correctness' of a rational scientific approach permeates the discipline. (Q5,Q6,S1,Comments)
4. A perception of OR as an approach rather than a toolkit is dominant. (S1, Comments)

In addition to the above, there is conflicting evidence concerning both the expressed level of confidence in the tools and techniques used (Q6,S1,S2).

By way of conclusion, the study can be viewed as providing a picture of modellers which emphasises their loyalty to the basic tenets of OR/MS whilst suggesting that they are, through their experiences, aware of some fundamental limitations in the techniques they have been provided with. In the context of technology planning, these findings supply a complimentary contribution to the results of the modelling activity reported in Chapters 3 and 4. Further to the critique of current approaches to handling uncertainty and the conclusion that modelling diversity in technological systems is problematic, there emerges the view that OR practitioners are both aware of the limitations of their models and seek to convey these limitations to decision makers. These findings will be shown to be of importance when considering the matching of strategic context with analysis technique selection (Chapter 10). Despite this, confidence in the O.R. 'approach' may serve to limit the development and application of alternative problem solving methodologies and techniques..

CHAPTER 8

PLANNING AND MANAGING RESILIENCE IN TECHNOLOGY INFRASTRUCTURE: POLICY IMPLICATIONS OF THE RESEARCH FINDINGS

8.1 Introduction:

The research activities reported in the previous five chapters have addressed various aspects of the core thesis issue. Chapters 8 and 9 constitute an integration of the research findings to generate conclusions and comment at two levels of interest. In the opening chapter of this thesis (§ 1.5.2), a distinction was made between the content of prescriptive measures (the 'what do do' questions) and the application of such measures (the 'how to do it' questions). Distinguishing between those conclusions that identify courses of action (policy inferences) and those which reflect issues concerned with *how* to analyse and assess various elements of these action programmes (methodological inferences) constitute an important feature of these last three chapters. The aims of the research programme can be viewed as reflecting both these types of issues as the study is concerned as much with the techniques of formal analysis as with the utility associated with various forms of technology investment strategy. From this typology of the research results, each research activity can be viewed as having a normative / positive and policy / methodological bias.

Modelling activity: Comprises both methodological and policy related findings but is positively biased towards a normative contribution rather than a positive one.

Israel Survey: As with the modelling activity, the survey of modellers and decision makers in Israel provides both methodological and policy related contributions. However, it is strongly biased towards positive inquiry rather than normative investigation.

Survey of O.R. practitioners: This element of the research programme can be viewed as being biased towards both positive and methodological results.

The pertinence of these biases resides in providing an indication of where each activity's contribution lies. The study as a whole is biased towards an appreciation of the methodological aspects of the research issues. However, information is drawn from both normative and positive sources, emphasising the interdisciplinary nature of the thesis.

The interdisciplinary approach which was deliberately fostered throughout the study is well suited to providing answers to both these types of issue. Such an approach is relevant to this study on two counts.

- The focus of concern is at the policy level.
- Initial research into the sources of planning failure, (the review of the nature of risk and uncertainty presented in Section 2.3), exposed cross disciplinary incongruencies.

Consequently, this Chapter is concerned with issues of policy which emerge from the modelling activity (Chapters 3 and 4) and the Israel survey (Chapter 5). The following chapter deals with a number of methodological points which can be identified as a result of all three research activities. Finally, in Chapter 10, an overview of the thesis' contribution is presented, drawing on aspects of both policy and method. The following two subsections constitute an introduction to these last three Chapters by providing a summary of the research questions and research findings.

8.1.1 A review of research aims and questions.

In order to provide the grounding for an evaluation of the research programme's findings and any subsequent conclusions, it is desirable for a thread to be illustrated between the following elements of the study:

- (i) Incentives for the research programme.
- (ii) Intents of the research programme.
- (iii) Derivation of research questions.
- (iv) Design and execution of research activities
- (v) Results of the research activities.

As a broad indication of the driving force behind the research undertaken in the preceding chapters, Chapter 1 identified the issue of exposing those methods and techniques by which society can ensure the reliability and affordability of basic resource supply in the long term. Emergent from this concern came a general research problem which was articulated in the following way.

"How can the characteristics of sustainable technological systems be identified, engendered and effectively managed ?"

After identification of the central determinants of this policy issue (both Chapter 1 and Chapter 2 include a discussion of relevant influences), three secondary research questions were proposed:

Secondary research question #1

'To what extent can the cost effects of a diversified technology base operating under turbulent conditions be effectively modelled and if so, what are the major aspects of diversity that are responsible for any increase in utility.'

Secondary research question #2

'What management planning and control strategies are adopted by modellers and managers operating in a turbulent environment ?'

Secondary research question #3

'To what extent are O.R. practitioners aware of the limitations of the techniques they use, particularly with regard to uncertainty representation, and how do they view the benefit of their activities to the organisation.'

8.1.2 Summary of policy related findings from the research activities.

Reference to Figure 1.1 should be made throughout the following two chapters so as to aid location of the discussion and contribution at the various levels of relevance (policy, methodological etc.). A major component of the thesis' contribution is in its examination of three distinct but equally influential elements of a core policy issue. With reference to Figure 1.1, the interfaces between the policy issue and the three elements (modelling, modelling practitioners and management strategy in a turbulent environment), constitute three perspectives, each of which has a contribution to make to policy formulation. The findings from each perspective in isolation constitute one level of analysis. Exposing areas of commonality, conflict, and synthesis between these perspectives constitutes a second level of analysis; one which is of greater use in policy formulation.

It is intended that this chapter should integrate the evidence collated from the research activities so as to focus the thesis upon the relevant policy issues; that of planning long term technology infrastructure. Reviewing the core findings from the research activities and using Figure 1.1 as a contextual template, an evidential map for use in presenting the study's policy related findings can be generated. Table 8.1 depicts a summary of research activities with the main policy related findings from each activity.

Table 8.1 Summary of research activities and evidential findings related to policy issues.

MODELLING ACTIVITY	
1.	Diversity of technology cost base, as represented by redundant capacity, may be beneficial in terms of total system costs and cost stability over long time horizons. The operating environment within which such benefits are likely to occur are characterised by cost function turbulence.
2.	The benefits of a strategy based on diversification are highly sensitive to several trends including the frequency and length of plant use, relative differences in cost profiles between technologies, the interaction between capital and operating costs, and the timing of investment and technology operations activities.
3.	Some technological characteristics have a relatively low influence on the benefits of a diversified technological system, including economies of scale, lead time to build, and efficiency levels.
4.	The existence of multiple states exposes the possibility that there might be several equifinal 'pathways' by which a given total cost state may be reached.
SURVEY OF MODELLERS AND DECISION MAKERS OPERATING IN A TURBULENT ENVIRONMENT	
1.	Criteria for decision making under turbulent operating conditions reflect issues of flexibility, consensus and feasibility.
2.	The focus of flexibility in such circumstances is on human resources.
3.	There is evidence for an altered set of goals associated with strategies which emphasise flexibility, focused on survival.

The following sections address these policy related issues, taking each in turn and discussing its implications for policy formulation. It should be stressed however that the information and comment contained in this chapter must be considered in tandem with that presented in Chapter 9. The advantage, indeed the *raison d'être* of an interdisciplinary study such as that contained in this thesis, is to expose the relationships and incongruences between various aspects of an issue. Consequently, some of the seemingly positive contributions contained in Chapter 8 are offset by methodological difficulties which are highlighted in Chapter 9. These perspectives are integrated in Chapter 10 where an overview of the research contribution is provided.

8.2 Assessing the potential of modelling resilience in technological systems as a policy tool.

The modelling activity reported in Chapters 3 and 4 began by developing a critique of current approaches to representing uncertainty in formal modelling processes. These were found to be strongly influenced by both a standard distinction between risk and uncertainty and the influence of a mechanistic approach to the development of analysis methodologies. Subsequently, a revised appreciation of the nature of risk and uncertainty was developed, attributing distinct characteristics to each and using these to examine meaningful ways of analysing their influence and effects on the planning function. As a result of this reinterpretation, an alternative approach to addressing the undesirable effects of uncertainty focused on diversity and adaptiveness was identified and its main attributes portrayed. The modelling activity itself addressed the issue of modelling diversity (as represented by technological redundancy) and resilience in technological systems and entailed the development of three simulation models (one spreadsheet based and two 'C' programme based) with which to investigate the relevant problems. The use of the models in this context is as a tool for learning, as outlined in Section 3.3..

8.2.1 Benefits of diversity in terms of total cost reduction and cost stability.

The modelling activities suggested that there are benefits to be derived from the adoption of a technology investment strategy focused on diversity (as measured on a cost basis and represented by redundant capacity), under certain cost conditions. These benefits may be in the form of lower total costs over extended time periods (§ 3.4.2), or in the form of greater year on year cost stability (§ 4.5). In the first of these processes, benefits accrue as a result of the diversified technological base facilitating change by providing options for operational activities. Options are represented by redundant plant which is maintained in a dormant state, ready for activation when cost conditions become advantageous. Greater year on year cost stability is achieved through more frequent but regularly spaced and less costly construction events occurring. This is an indirect rather than a direct outcome of the adoption of a strategy of technology diversification. Cost conditions under which a diversification strategy is beneficial are typified by both turbulent cost profiles and situations where one technology's cost profile undergoes a radical transition.

It should be noted that a particular class of problem within the field of assessing resilient technological systems has been addressed and the results obtained are context specific. Despite this caveat, there are several points which are of interest in formulating policies for long-term technology infrastructure investment. Firstly, the benefits of diversity in the context examined are highly dependent upon the nature of cost turbulence which is experienced by the organisation. The two programmed models (Divers(x) and LTIME) were put through multiple runs due to the stochastic nature of the cost generation algorithms. It was found that relatively small changes in initial parameters resulted in large differences in the utility associated with the strategy of diversification. From a policy perspective this result suggests that the operating environment itself should form as important an element of analysis as does the organisation and its constituent parts (technologies, organisational structure, human resources, finance etc.). Strategies based on technology diversity may not be well suited to relatively stable operating environments. The model results suggest that for a diversification strategy to be effective from a cost perspective, opportunities must arise (and arise frequently), for technology substitution. This may not necessarily occur through cost profile turbulence, and other technological attributes such as maintenance schedules and reliability issues may have an important effect on the efficacy of diversification.

Cost stability is an issue which may be of concern in several policy areas. For example, developing countries often desire some measure of consistency in infrastructure technology cost performance to provide a robust basis for the development of other industries. Similarly, the types of industries which form the focus of attention for this thesis (utilities such as water, electricity and gas supply) are often under pressure from government to ensure stable pricing policies. The model results reported in Chapter 4 suggest that investment in a diversified technology base may be one way of both providing consistency in yearly total costs, and narrowing the spread of possible cumulative costs (over 50+ years) under turbulent and uncertain operating conditions.

8.2.2 Key sensitivities in the utility of a diversified technology base.

An additional finding of the modelling activities provides a note of caution to the above outlined policy conclusions. The utility associated with a diversified technology base was found to be highly sensitive to changes in certain key parameters. These include the frequency and length of plant use, relative differences in cost profiles between technologies, the interaction between capital and operating costs, and the timing of investment and technology operations activities.(§ 3.4.2). The frequency with which particular items of plant are brought on-line and the length of time for which it is used dictates the system's operating cost profile. Cost benefits from switching are a function of several interacting parameters:

- The trade off between the operating costs of the original and substitution technologies.
- The costs of switching between two alternative technologies.
- The number of switch events.
- The magnitude of saving which accrue from each switch event.

It was pointed out in section 3.2.4 that whilst the first and second of these parameters can be assessed at the time of switching, the latter two are indeterminate as they rely upon the lifetime performance of the technology and future trends in the relevant cost functions.

The models did not directly address these operational issues and it is therefore difficult to comment any further on the nature of the sensitivities. What is clear however, is that relatively minor changes in the parameters listed above can have a significant effect on the overall utility of adopting a strategy of technology diversification. Hence, there are a range of operational as well as investment factors which policy makers need to consider when assessing the usefulness of diversity as an investment criteria.

From a policy perspective, the identification of sensitivities is of importance in relation to system design. If generic (technology independent) sensitivities can be isolated, then technologies could be designed for operation in a diversified technology base. The discussion presented in the following section on the relative importance of systemic properties over individual plant attributes is also pertinent to this issue. Given an altered focus for analysing technological attributes, technology design could be guided by system level concerns rather than individual plant attributes, thereby enhancing overall system performance. Referring back to the results of the modelling activity for an example, technologies could be designed to lower the cost and increase the speed of substitution, two parameters which were found to have a significant influence on the cost performance of a diversified system.

8.2.3 The relative significance of systemic properties over individual plant attributes.

In contrast to those parameters which cause major changes in the utility of a strategy focused on technology diversity, a number of factors were identified during the modelling activities that have little effect on the overall benefit / disbenefit of a diversified technology base (§ 4.3). These factors include plant age (as represented through decreased efficiency), lead time to build, and plant scale. Although these parameters were initially considered significant (as suggested by several published sources), their influence becomes relatively unimportant within a system which relies for its overall cost performance on the interplay between two or more sets of operating costs. This feature of the modelling output raises an important issue concerning the relative effects of individual plant and system effects on total cost trends and cost stability. Within a diversified technology system such as that modelled, system characteristics rather than individual plant attributes appear to be influential in determining system cost profiles. It is the interplay between various aspects of the system (as discussed above in relation to the sensitivity of benefits to key parameter changes) which dictates the cost performance of a diversified technology base.

There are a number of policy and methodological issues emergent from this finding (see Chapter 9 for a discussion of the methodological aspects). In relation to policy formulation, the need for a systemic (multiple unit / multiple influences) analysis of cost performance may broaden the scope of technology planning to include wider aspects of

the problem such as complimentary technology design (see previous section). A particularly interesting aspect of this element of the modelling results shows that the two parameters of lead time to build and plant scale become of marginal cost importance within a diversified system. The explanation for this lies in the type of diversity represented. Holding redundant capacity allows new plant to be constructed without the need for hard and fast completion dates. As long as there is enough capacity to meet demand, new plant can be constructed at an even-tempered pace. Similarly, diversity and redundant capacity in combination dictates low individual plant capacities in relation to total demand. The actual size of plant capacity did not appear to be a notable influence on either the total cost profiles or the utility of the diversified technology base over a single technology base. However, the models did not pursue this aspect of the simulation in any depth and there is scope for further work on the relationships between plant size, plant type, and system attributes.

As an appendix to this discussion, the identification of the relative significance of systemic properties over individual plant characteristics highlights the benefit of using the alternative view of risk and uncertainty outlined in Chapter 2. Rejection of the mechanistic approach and the development of a revised framework for investigating the core policy issue results in the emergence of new dimensions to problem framing and subsequent options for action.

8.2.4 Equifinal states and the concept of pathways.

The final policy issue to emanate from the findings of the modelling activities concerns the phenomena of equifinal states (more than one time series leading to a given final or transitory state), which were observed during the running of the programmed models. This aspect of the modelling results is somewhat more speculative than those discussed above. However, it does have important policy implications and a presentation of its potential employment in policy formulation is therefore given with references to some previous conceptual work.

Whilst the phenomena of equifinal states can be directly attributed to the combinatorial aspects of the mathematics involved in the model structure, the pathways which lead to these states constitute significantly different event sequences. Identical end states on a cost basis could represent significant differences in the types of technology operated, investment sequences, yearly total cost profiles and other parameters. The experience, or process, of system evolution can thereby be taken as an additional criteria for strategy selection.

The idea that there may be several pathways via which a similar end state can be reached was posited as a theory by Bertrand de Jouvenel (1967). Selection of one pathway (or set of pathways) may be influenced by the experiences associated with traversing that option. As mentioned above, the possibility of identifying stable pathways of system evolution may be particularly useful in relation to developing countries. In such arenas the motivational influences of profit and/or competition are often restrained and there is a higher emphasis on the provision of a firm footing for socio-economic development. However, the results presented in Chapter 4 appear to

suggest that any attempt at defining and following closely bounded pathways is a highly risky practice. This raises a set of issues relating to the identification of nodes where effective policy changes can be executed, thereby promoting flexibility. Perhaps the most appropriate reference point for this element of the study are Sperling's contributions (1982, 1984). Whilst this strand of research is mainly concerned with an analysis of technological change, it also emphasises the need for a broader assessment of system evolution.

'Pathways transcend the narrow criteria of economic and engineering efficiency to incorporate a wide range of human desires, ideals, and conflicts into the planning and analysis of technological change.' (Sperling 1984).

Consequently, the concept of pathways and in particular of equifinal paths of development deserve further effort on a research basis. Indeed, if the models described in Chapters 3 and 4 are to be developed and improved, the analysis of various aspects of stable system evolution and pathways could form one focus of effort.

8.3 Management in a turbulent environment: Policy implications of the need for resilience.

The survey of managers in Israel was designed to ascertain what management planning and control strategies are adopted by modellers and managers operating in a turbulent environment. A questionnaire and semi-structured interview survey was designed and executed, the results of which are presented in Chapter 5. The data collated from the survey are relevant to a discussion of policy formulation because it provides empirical evidence of actual strategies which are adopted under turbulent operating conditions. The significance of such conditions was highlighted in Chapter 1 as being typical of the operating environments of technological infrastructures over extended time periods. Policy formulation based on the 'predict and prepare' approach to planning is likely to be found wanting under turbulent operating conditions. The survey results thereby provide an indication of what alternative management approaches are adopted, or developed, under such conditions. Three particular findings from the Israel survey can be located within a policy framework; the criteria for plan or project adoption, the sources of key organisational attributes, and the nature of strategic aims. Each of these is addressed in turn in the following three subsections.

8.3.1 Criteria for project or plan adoption.

The survey of managers and modellers in Israel found that criteria for project or plan selection reflect issues of flexibility, consensus and feasibility (§ 5.6). Projects were found to be selected on the basis of their ability to be changed or altered at a later date. Furthermore, the perceived feasibility of the plan and the attainment of consensus amongst the management team were major factors influencing the adoption of investment or other activities. Whilst this evidence was mainly anecdotal (coming from the survey interviews rather than the questionnaire responses), the unprompted nature of

the responses make this a sufficiently robust finding to be addressed here.

The nature of flexibility has been discussed earlier in this thesis (§ 2.9.3) and it is only relevant here to note that respondents did not show any appreciation of the distinction made in Chapter 2 between adaptivity and flexibility. The issue of project feasibility could be interpreted as relating to low levels of risk exposure (i.e. the likelihood and cost of being wrong [§ 2.7]). However, in this context it is speculated that feasibility has more to do with a perception of how practicable the project is, and that it is one aspect of the desire for consensus. Chapter 5 also drew attention to a dominant management style which was emergent from the study and provided other published references which support this finding. Consensus is promoted by a shared belief in the achievability of a project and a negotiated management style would enhance the process of achieving such agreement. Generally, the three criteria of flexibility, feasibility and consensus are reflective of a management style which concentrates on a negotiated approach to problem solving and the promotion of adaptive response.

8.3.2 Human resources as a source of flexibility.

The finding that the most important sources of perceived flexibility in organisations operating in a turbulent environment are human centred in nature, suggests that human resources should be a key element of strategies which seek to promote resilience. Whilst the organisations surveyed in Israel all had large technological components, management still perceived the flexibility of their human resources to be of primary importance. This flexibility was characterised by a willingness to take on a variety of tasks or roles and an emphasis on training and education.

The ramifications of these findings for policy formulation are mainly concerned with the relative emphasis which organisations put on investment in technological and human resources. If resilience is affected more by human focused elements than by technology or system design, then there may be little relative benefit to be gained from detailed analyses of technology cost and performance. Therefore, with regard to this study's focal issue, there is some encouragement from this finding to prompt research into the relative effectiveness of human and technological flexibility in the context of long term technology infrastructure planning and operation. Such a study should not limit itself to the cost aspects of the issue (see following section), and should include an assessment of the influence of technology cycles.

Human resource flexibility has been taken up as a policy issue in Europe and the USA (Bramble, 1988). There is however a major source of incongruence between the Israeli and Japanese approaches on the one hand and applications of concepts of flexibility in Europe and America. The results reported in Chapter 5 show that the flexibility of human resources from an Israeli management perspective lies in the multiple attributes of individual employees. As mentioned in Section 5.5, this is also the case in Japan (Ishida, 1986), where job descriptions are often vague and employees are expected to be flexible in their role behaviour. Conversely, flexibility has been introduced in European and American contexts in the form of contingent workforces where skills are selected from a 'pool' of specialist labour as and when required (Belous, 1989). This is clearly a

different interpretation of what constitutes a flexible workforce. Although its immediate benefits may be readily appreciated, the long term effects of temporary workforces with high degrees of specialism have as yet only been speculated.

8.3.3 Is the promotion of resilience merely a survival strategy ?

The final policy related finding to emerge from the Israel survey concerns the identification of an alternative set of aims and goals for the organisations surveyed. These aims are centred around issues of survival and alternative roles for the organisation itself, outside of being a wealth or profit generator. Like the issue of plan adoption criteria discussed in Section 8.3.1, the evidence for alternative organisational goals comes from the interview component of the survey. However, its policy implications are sufficiently interesting for it to warrant some discussion here.

Survival as a desirable organisational aim is attracting increased interest in a number of fields (e.g. Mitra & Roy, 1993). Its relevance to this study is in relation to the discussion of consistency of resource provision presented in Section 1.3. Survival in this context can be interpreted as the continued achievement of minimum levels of consistency. Diversity in any form is an option source. Coupled with the ability to take advantage of such options (adaptability), diversity constitutes a tool for ensuring the continuation of system operation rather than a method for achieving maximum performance. System survival may, of course, be defined in many different ways (for example as the achievement of a minimal profit margin or the continued supply of a specific good). In the field of biology (where the analogy is drawn from), survival is associated with existence. The relationship between survival and elements of resilience such as diversity and adaptability requires more investigation before the relevance of the analogy in terms of technological systems can be fully addressed. Chapter 1 mentioned the dangers inherent in adopting analogies from other fields and stated that care needs to be taken if the associated 'baggage' from biological science is not to be drawn into more general assessments of resilience. Despite this, the evidence for survival as a goal for resilient systems suggests that this particular piece of baggage can not be so readily ignored.

Finally, it is not insignificant that the emphasis on survival is associated with a situation where human resources are considered an important element of organisational effectiveness. The direction of cause and effect between these two phenomena are open to speculation. However, alternative criteria for success (e.g. maintaining employment levels or the 'viability' of the firm), allows human factors to be emphasised over technological ones due to the reduced influence of cost considerations on measures of success. This suggests a link between criteria for success and key components of that success, a proposition which may explain the particular interpretation of a flexible workforce adopted in Europe and the USA that was highlighted in the previous section. Stated more precisely; if organisational goals are calibrated in monetary terms, the key influences on the ability of the organisation to achieve those goals will be cost based. Alternatively, if the goals are concerned with broader social issues, key influences on success will have more human centred biases.

8.4 Summary and conclusions.

This chapter has drawn together the policy related findings of the research activities reported in Chapters 3-7. Emergent from these findings, a number of distinct policy issues have been discussed which prompt the following policy level conclusions.

Policies which focus on technology diversification as a means for achieving resilience need to pay attention to

- a) The relative importance of system level behaviour over the behaviour of constituent elements of the system.
- b) The possibility of reformulating technology design criteria to promote characteristics which might enhance the performance of the system as a whole. (Hierarchical aspects of system performance are particularly important here.)
- c) Altered criteria for system aims such as survival and the continuation of minimum performance levels.
- d) The possibility that there may be more than one path via which a desired system state may be achieved.
- e) The relationship between the benefits of a diversified technology base and the nature and levels of turbulence in the operating environment.
- f) The relative importance of human centred factors in achieving resilience by way of flexibility and adaptivity.

These conclusions will be taken up in Chapter 10 where they will be integrated with the results of Chapter 9 to form an interdisciplinary contribution to the core policy issue. The following chapter goes on to address the methodological issues which emerge from the research activities.

CHAPTER 9

PLANNING AND MANAGING RESILIENCE IN TECHNOLOGY INFRASTRUCTURE: METHODOLOGICAL IMPLICATIONS OF THE RESEARCH FINDINGS

9.1 Introduction

The intent of this chapter is to review the methodological implications of the research findings. Inferences of this type were generated by all three research activities and Table 9.1 (below) summarises the contribution of each one. The methodological findings provide information concerning the tools, processes and individual perceptions which contribute towards formal planning procedures. These are the 'how to do it' questions which were identified in Section 8.1. The contribution of the discussions presented below is concerned with both highlighting areas of interest in relation to planning for resilience, and providing an appreciation of the difficulties associated with planning under uncertainty. The findings reported in this chapter are used in conjunction with the contribution of Chapter 8, to generate an integrated interdisciplinary contribution to the area of technology infrastructure planning in the following chapter.

Table 9.1 Summary of research activities and evidential findings related to methodological issues.

MODELLING ACTIVITY	
1.	The modelling activity itself demonstrates that issues of diversity and adaptability can be modelled using both a spreadsheet and programming language base.
2.	Increased complexity of the model was not matched by significant additional insights into the policy aspects of operating a diversified technological base.
3.	Despite the evidence from early versions of the model, use of the capital / operating cost ratio as a technology characteristic indicator was found to be problematic.
4.	The issue of multiple solutions (resulting from the use of stochastic cost functions) constitutes an extra dimension to analysing the utility associated with a diversified technology base.
SURVEY OF MODELLERS AND DECISION MAKERS OPERATING IN A TURBULENT ENVIRONMENT	
1.	Sources of perceived turbulence are mostly outside the influence of the organisation. Information regarding trends in the operating environment is gathered from informal sources.
2.	Formal decision support techniques have a limited influence on decision making.
3.	Determinants of the approach to handling uncertainty have a significant cultural element.

Table 9.1 contd.

SURVEY OF OPERATIONAL RESEARCH PRACTITIONERS IN THE U.K.	
1.	O.R. practitioners are aware of the limitations of the tools and techniques which they utilise.
2.	O.R. practitioners are keen to communicate these limitations to other organisational actors.
3.	There is a widespread view of O.R. as providing a rational, scientific approach to organisational problem solving.
4.	O.R. practitioners perceive their profession as an approach rather than as simply a collection of techniques.

The following three sections take each research activity in turn and discuss its main findings in the context of their methodological implications.

9.2 Some problems associated with modelling diversity in technological systems.

The modelling activity, whilst being primarily concerned with an investigation of the behaviour of diversified technological systems under turbulent operating conditions, provides a number of methodological findings. These arise mainly from the modelling process itself which resulted in several non-trivial complications being identified as the model was developed. Some of these complications constitute obstacles to the development of models of this type whilst others can be seen as opening up alternative avenues for investigation.

9.2.1 The suitability of the developed simulation models as tools for representing aspects of diversity in technological systems.

The modelling activities demonstrated that both spreadsheet software and programmed simulation models provide effective vehicles for modelling aspects of diversity and adaptability in technological systems. The initial spreadsheet model enabled a number of issues to be investigated including the effects of lead time to build and timing of operating cost increases on the utility of a diversified technology base. Experience of developing the spreadsheet model suggests that additional parameters and relationships could have been investigated at this relatively simple level. The advantages of the spreadsheet as an investigative tool include the ease and relative speed with which relationships can be represented and analysed, and the clarity of output which arises from having the graphics functions integrally linked to the calculation routines. In retrospect, further use could have been made of the spreadsheet model to provide an initial investigation into a wider range of the issues addressed with the programmed model. Specifically, the spreadsheet and 'C' programmed models could have been developed concurrently, allowing a measure of interplay between the two and improving the overall efficiency of the modelling activity.

The translation from spreadsheet based model to programmed model was initially carried out in order to speed up the analysis process, to increase the scope of the research, and to allow a greater range and complexity of parameters to be assessed. A significant methodological research finding in this context is that the increased complexity of the programmed models did not generate significant additional insights into the policy related aspects of the research. This is not to say that the 'C' programmed versions of the model were not productive; they exposed several methodological problems which inform the contribution of this thesis (see below). However, the evidence from the modelling activities suggest that increasing model complexity is not necessarily the route to clarity and understanding. Some additional support for this view is forthcoming from the Survey of O.R. practitioners in the U.K. where increased model complexity was often considered unlikely to improve the quality of output.

The models developed using the 'C' programming language (see Appendix 1 for listings), proved to be capable of representing diversity through redundancy, and of generating a variety of relevant system performance data as output. It should be remembered that the modelling approach used involved the simulation of a set of technological and cost attributes and an examination of aggregate cost trends under two investment strategies. Diversity was implied by redundancy and adaptability was assumed to be possible at all times. Several advantages from using this type of model can be identified.

Model structure was modular in nature, with several separate blocks of code being written to execute various functions within the model. This was found to be an advantageous approach to the modelling activity as it both facilitated error checking and enabled the model itself to evolve in response to new information. The modular structure was also particularly useful in allowing emergent issues to be addressed with relatively small changes to the code. Finally with respect to the structure of the model, a modular approach means that the model is able to be further developed, if required, in an iterative manner, adding or improving specific elements of the model with relative ease.

A further advantage of the modelling approach adopted concerns the ability of the model to address both parameter relationship and decision issues. The decision algorithms which were incorporated in both the LTIME and DIVERS(X) models involved an assessment of the need for new plant investment based on an analysis of current demand, and the age and operating history of each item of plant. Although the decision algorithms were used in those model runs reported in Chapters 3 and 4, the full potential of this particular function was not exploited. There is therefore scope for expanding this aspect of the work to include more complex decision problems involving a wider range of parameters.

Perhaps the most significant technique oriented aspect of the modelling activity is the method used to generate dynamic cost functions. Appendix 1 provides a detailed account of this approach which uses superimposed cubic functions and regime switches

to generate a time series with turbulent behaviour. The principal benefits of its application include the ability to control the macro level features of the time series whilst maintaining a random pattern of year on year cost values.

Deficiencies in the modelling approach are mainly concerned with limitations on the application of the output. By selecting cost and technology attributes as the focal parameters for the model, its range of applicability is restricted to a specific class of problems. Furthermore only a specific type of diversity was examined and although the results obtained are valid within the confines of the study, they say less about diversity and resilience generally. Hence, as a conclusion on the suitability of simulation models, it must be said that the experiences of the research activities have been encouraging but are very much context specific.

9.2.2 Parameter representation and the value of model output.

It was reported in Section 4.3 that graphical representation of the model output was hindered by the ambiguous trends observed in two model runs with very similar initial conditions. This particular problem was partially responsible for bringing the modelling activity to a halt. Capital / Operating cost ratios were identified in the spreadsheet model as a useful technology characteristic measure when assessing the attributes of diversity. However, this measure proved to be unstable in the 'C' programmed model due to the influence of aggregated relative movements in the capital and operating cost profiles. Various alternative aggregates of technology cost were applied as model output measures but none generated sufficiently reliable results to enable continuation of the modelling activity. It may be that the interactions between plant and system attributes are more complex than the model reported in Chapters 3 and 4 were able to expose. However, a simpler explanation attracts support from a detailed investigation of the modelling output. Any aggregated cost profile (whether via summation, product or vector), cannot represent a unique history of a technology or group of technologies. A measure of the relationship between capital and operating costs loses specificity for the sake of generality. Therefore, the concentration on individual technology cost parameters may, in hindsight, have been a mistaken choice for a parameter against which to measure the utility of a diversified technology base.

The emergence of this problem has three ramifications for methodology. Firstly it raises the question of what attributes of a technology can be used to assess its suitability for inclusion in a diversified technology base. In Chapter 8 it was suggested that the identification of such attributes would enable technologies to be designed from the point of view of their contribution to the systemic aspects of diversified systems (§ 8.2.2). The difficulties experienced in identifying cost parameters, the interpretation of which remain stable during model output, poses a problem for the identification of these attributes. Further work on this issue may benefit from a closer analysis of the interactions between cost and technological attributes in this context.

Secondly, a wider issue of system state representation is exposed by the problem of non-

unique parameter measures. Measuring and representing system attributes is a process of simplification and structuring (as discussed in § 2.2.1). Representing every single parameter in something as complex as a technological system is beyond the means (or time ?) of current methods and tools. Hence, aggregation is adopted as a simplifying measure. Working backwards from model output to identify the particular configuration of the model's constituent elements which results in some optimal state or behaviour is consequently problematic. This is due to both the aggregation which has necessarily taken place, thereby losing specificity, and a failing to take account of the history of system performance or evolution. This is a very general point, but one worth noting in the context of modelling activities of this type.

Finally, isolating a data presentation technique which satisfactorily represents the information acquired from the model exposes the sensitivity of the data to multiple interpretations. The discussion presented in Appendix 1 with regard to the selection of a relevant surface gridding method illustrates this point. Data representation is an important aspect of the modelling process, both with regard to clarity of presentation to decision makers and effective interpretation by modellers themselves. Having developed a relatively complex model and wishing to maintain the ability to access a variety of output parameters, selecting two or three for depiction presented many difficulties. Specifically, two or three dimensional graphical representations are incapable of providing the richness of inter-dependencies which exist. This point was emphasised during the modelling activity where the exposure of the multiple solution problem was only resultant from a detailed (two day) examination of an output sequence which had to be disaggregated in order to isolate key variable relationships.

9.2.3 The phenomenon of multiple solutions and its effect on modelling diversity.

Sections 3.3 and 3.4 presented a discussion of the phenomena of multiple solutions which was encountered during the modelling activity. This circumstance occurs where one x,y point on the utility surface (representing a technology cost configuration), possesses more than one 'z' value (representing total cumulative costs over one run of the model). In the particular case of the models depicted in Chapters 3 and 4, the cause can be traced to the equifinality of aggregated cost sequences which formed the basis for the measurement parameter represented on the z axis. (It is useful to bear in mind that multiple solutions should not be viewed as an end state phenomenon. They are just as likely to occur during the time series as at the end). During the modelling activity multiple points were averaged to obtain a single value for use in the surface generation programme. Multiple solutions are a direct result of executing repeated runs of the model to achieve a stochastically robust picture of system performance over a range of operating conditions. Utilisation of this method reflects a view that the future may unfold in any one of a number of possible ways.

There are a large number of issues emergent from the phenomenon of multiple solutions, many of which are concerned with the theory of modelling itself. Most of these issues are inappropriate to a discussion of diversity and long term infrastructure

planning. Two points are however deserving of some note in the context of this research project's subject matter. Firstly, both the number of possible end states and the frequency of multiple solutions will be a function of the number of time steps over which simulation is carried out (as demonstrated in § 4.4). Extended time horizons for analysis purposes are thereby associated with increased variety of possible solutions and a resulting need to apply some bounds to the analysis. The number of possible end states also increases with the number of related variables used. Again, increasing the complexity of the model (via the connectivity of parameters) results in a corresponding increase in the complexity of the output measures. From a methodological perspective, these trends suggest that parameter interaction and aggregation can adversely influence the clarity of model output, making interpretation problematic.

The significance of multiple solutions in a policy context was discussed in Section 8.2.4 where the potential for their exploitation as indicators of stable system configurations was outlined. However, as a second implication, the methodological aspects of the phenomenon suggest that alternative methods to simulation analysis may provide a more appropriate tool for analysing this sub-issue. For example combinatorial theory is a useful approach to this class of problem.

9.3 Management approaches to planning under turbulent operating conditions.

The survey of management and modellers reported in Chapter 5 was focused on organisations operating under turbulent environmental conditions. The intent of the survey was to expose those management planning and control strategies that are adopted by modellers and managers operating in a turbulent environment. Data collated from this survey provide several points of interest concerning the planning methods which are found advantageous under such conditions. The findings are particularly relevant given the discussion presented in Section 9.2 concerning the limitations to modelling diversity as a component of resilience.

9.3.1 Management information sources and environmental turbulence.

Section 5.6 contains evidence which shows that the main sources of environmental turbulence which are of concern to Israeli managers are mainly outside their ability to either effect or control (e.g. Government policy, cost of capital and exchange rates). An associated finding showed that very few organisations engage in forecasting of any sort and that environmental monitoring is pursued by way of informal rather than formal means. These results suggest that high levels of environmental turbulence do indeed diminish the effectiveness of the predict and prepare approach as was proposed in the introduction to the survey (§ 5.1). Managers and modellers in Israel have been faced with a continuously turbulent environment since the state's inception in 1948. This has led to the emergence of alternative approaches to planning which would be unlikely to be found under conditions of relative stability.

With regard to the development of useful methodologies, the emphasis on informal information gathering is one element of a tangible management style which was identified during the study. There was no indication during the survey of any structured approach to information retrieval, indicating that methodical information collection and collation does not significantly contribute to formal management operations. No evidence was sought to explain these trends but it is understandable for organisations to restrict formal information and forecasting operations under conditions where such data are likely to be inaccurate due to continuing economic and political change. The benefits of accessing informal sources of information may be connected with maintaining personal contact with other management and staff. This would allow a contemporary picture of staff attitudes and beliefs to be built up, significantly increasing the ability of management to achieve the consensus which was highlighted in the previous chapter (§ 8.3.1). Furthermore, informal information gathering is not restricted by any pre-set analysis framework, allowing management to selectively screen data sources for relevant facts or opinions.

As mentioned above, a distinctive management style was identifiable in Israel. The methodological implications of the study are very much focused on this style and further comments on the methodological implications of the findings is therefore deferred until other aspects of the approach have been discussed.

9.3.2 The contribution of formal decision support techniques under conditions of environmental turbulence.

The survey of Israeli management found that formal decision support techniques (modelling and associated activities) have a limited influence on decision making. Decisions were affected more by the manager's subjective assessment of the situation than by the contribution of rational / scientific analysis techniques. This is a further indication of the management style alluded to above and reflects a desire to include a wide range of sources of information as contributing elements to a decision. Although no direct evidence was collected which demonstrates the ineffectiveness of formal analysis techniques in this setting, the propensity of decision makers to treat their contribution with caution suggests that other methods are considered more effective.

Extrapolating the points raised in this and the previous section for use in other situations is restricted by additional findings reported below (§ 9.3.3). Additionally, without further evidence it is difficult to associate the information gathering style of Israeli managers with any specific type of benefit or utility. What is clear however, is that turbulent operating environments generate management approaches which are characterised by a move away from attempts to predict future states of the environment towards informal information gathering and a reduced role for formal modelling and other decision support methods.

9.3.3 Determinants of Israeli managers' approach to handling turbulent environments.

Several strands of evidence collected during the Israel survey suggested a cultural dimension to the general approach to uncertainty which is exhibited by Israeli management (§ 5.6.2). Specifically, a history of uncertainty, during both the Diaspora and the existence of the State of Israel, has imbued an acceptance of unforeseen change and surprises. Hence, there is a suggestion that uncertainty has become an accepted part of Israeli life, leading to the development of methods and procedures which reflect a need for flexibility and adaptability. This proposition is supported by the fact that whilst no formal methodologies focused on diversity, flexibility, or adaptivity were identified during the survey, the attribute of flexibility was stated as being a major contributor to organisational survival. This shows that if flexibility is a characteristic of a distinctive Israeli management style, its main elements are informal in nature.

A further important aspect of this finding from a methodological viewpoint is the emphasis put on the work-force as a source of flexibility. Again, no specific processes were identified which sought to promote such attributes and staff simply appeared to be expected to exhibit behaviour which enhances flexibility. This finding takes the subject matter outside the domains of this study and into issues of culturally determined attitudes and behavioural science. However, it is pertinent in the context of this study to note that the human centred aspects of resilience appear to be at least as important as technological or cost aspects. The planning of long term technology infrastructure may, as a result, need to take into account a number of training, management style and organisational structure issues if resilience is to be promoted.

9.4 The role and effectiveness of Operational Research methods as perceived by practitioners.

The survey reported in Chapters 6 and 7 was conducted in order to ascertain the perceptions of O.R. practitioners' concerning the role of their tools. The contribution of this element of the research is almost entirely methodologically biased. Chapter 2 presented a critique of current approaches to addressing uncertainty in modelling and associated activities that exposed some major limitations to the techniques and tools used. It also drew attention to the role of modellers as interpreters of the organisation's activities and its operating environment within formal analysis activities. The survey of modellers and decision makers in Israel (§ 9.3), exposes both a human centred aspect to management strategies under turbulent operating conditions, and a low level of influence for formal modelling and analysis techniques.

An additional dimension to the O.R. practitioner survey comes from the modelling activities. If the modelling of diversity and associated aspects of resilience are to be adopted as alternatives to current methods, there is a need for an assessment of how practitioners view their current techniques and whether they are aware of their limitations. The survey of modelling practitioners is intended to throw additional light

on modeller's own views concerning the validity and role of their techniques. The results of the survey provided a number of closely related findings and it is therefore considered appropriate to deal with this survey within one subsection.

9.4.1 Practitioner perceptions of their tools; the bounds to an awareness of limitations.

The O.R. practitioner survey exposes evidence which suggests that O.R. professionals are generally aware of the limitations of the models they use and are concerned to communicate these limitations to other organisational actors. These findings are reflective of the often vigorous debates which occur within the O.R. community concerning the role of the profession and the applicability of both established and novel techniques. An awareness of technique limitations suggests an ability to develop critical assessments of the tools which are either obtained during formal education or encountered subsequently.

However, there were also two pieces of evidence which serve to bound this picture of O.R. practitioners. Firstly, it was found that nearly a third of respondents had no reservation about using a particular technique for a specific task. Secondly, there is a strong commitment to the 'rational / scientific' approach as a fundamental benefit of O.R. These two findings provide limits to the awareness of limitations discussed in the foregoing paragraph. The survey did not ask respondents to illustrate what they meant by 'rational' or 'scientific' (the relevant questions were open ended and the terms themselves were posited by the respondents). Anything which falls outside this class of techniques however, is likely to be treated with suspicion by a community which demonstrates such a clear adherence to the principles of one scientific paradigm.

A more detailed look at the results of the O.R. practitioners survey helps to identify one particular source of possible conflict in relation to alternative approaches. There was evidence from the survey that those practitioners who did see limits to the technique they had adopted were mostly concerned with the representation of 'soft' or 'human' components. It was also found that the third most commonly noted disadvantage of O.R. techniques was that they ignore 'soft' or 'behavioural' issues. It will be remembered that the Israel survey highlighted the relative importance of human or soft aspects of flexibility over technological aspects. Herein lies a potential problem for the development of methodologies which assess attributes of resilience.

The decision making and management style which was evident in Israel does not emphasise any rational / scientific analysis, but rather focuses on intuition and negotiation. It is precisely the human centred emphasis of the Israeli management style (informal information gathering and consensus generating etc.), which promotes this sort of decision making. If strategies which promote resilience through flexibility and adaptability do indeed emphasise the softer elements of the organisation, it may be inappropriate for O.R. practitioners to be involved in their analysis.

This is a speculative comment, but one which is supported by both the results of the research and the recent history of the O.R. profession.. The O.R. community in the U.K. has been provided with tools which tend towards the softer methodologies mentioned above (many of which are expounded in Rosenhead, 1989). However, the emphasis placed on O.R. as an 'approach' rather than a toolkit (§ 6.2), has served to restrict the uptake of these methods. The classical 'approach' referred to in the survey results is that of applying scientific methods to industrial and business problems. This has led to what has been termed an "*obsession with quantitative modelling*" (Eilon, 1989). There is no evidence of obsession in the survey findings, but there is an indication that rationality and the scientific method are not only ingrained as an approach, but also seen as a major benefit. The 'soft' techniques which focus on human centred issues are closer to the field of organisational science and therefore meet with disinterest.

9.5 Summary and conclusions.

Chapter 9 has presented an overview of the methodological related findings of the three research activities. The information from these findings has been used to investigate some boundaries to the modelling techniques used in Chapters 3 and 4, and in a general discussion of methods for assessing and engendering resilience. The main conclusions regarding the methodological aspects of the study can be summarised thus:

1. Approaches to the use of simulation models for assessing the benefits of diversity in technological systems need to be informed by the following issues:
 - a) Diversity representation can be achieved by the modelling of redundant capacity.
 - b) A modular approach to model design can be beneficial with regard to both code formulation and run time problem resolution.
 - c) Output parameter representation needs to be unambiguous and result facilitate interpretation.
 - d) The use of stochastic techniques may introduce issues of multiple solutions.
 - e) Increased model complexity is not necessarily associated with significant additional insights into the problem.
2. Strategies which are found to be of use under turbulent operating environments are characterised by the following methodological elements.
 - a) Informal information gathering.
 - b) Consensus building.

- c) Decision criteria focused on achievability, consensus and maintaining options for change.
 - d) Emphasis upon the human centred attributes of flexibility and adaptability over technological elements.
 - e) A reduced role for formal modelling and decision support techniques.
3. The commitment of O.R. practitioners to a rational / scientific approach may make them an inappropriate group for assessing the softer aspects of strategies which seek to engender and manage resilience.

These conclusions, together with those from Chapter 8, are used in the following chapter to inform a discussion of the core research issue (ref. Figure 1.1).

CHAPTER 10

THE PLANNING AND MANAGEMENT OF DIVERSITY: PLACING THE RESEARCH FINDINGS WITHIN AN INTERDISCIPLINARY FRAMEWORK.

10.1 Introduction

Chapters 8 and 9 have presented the policy and methodological aspects of the research findings respectively. Relevant evidence from the research activities was structured so as to provide a framework for the assessment of each aspect within the context of the thesis' main research issue. This final chapter has two main aims. Firstly, the secondary research questions will be addressed and the contribution of the thesis to answering them outlined. Secondly, the interdisciplinary nature of the study as a whole calls for an integration of the various investigative threads in order to illustrate the thesis' contribution to the main research question. This is achieved by way of a conceptual framework which supports discussion and analysis of the relationships between the main themes of the study. In addition, areas of interest for future research will be suggested and briefly discussed.

10.2 Addressing the secondary research questions.

During a discussion of the thesis' main aims and objectives in Chapter 1, three secondary research questions were posited that provided sub-goals for the research activities (§ 1.3). The following three sections seek to directly address these questions in the context of the research findings. It will then be possible, by way of an interdisciplinary assessment of the total research contribution, to discuss aspects of the core research issue. The following sections thereby provide the constituent elements of the interdisciplinary level conclusions. Furthermore, they supply a number of useful conclusions in their own right and indicate potential areas of interest for subsequent research. Hence, the thesis contribution as a whole can be seen to occur on several levels of analysis.

10.2.1 Modelling diversity in technological systems:

Secondary research question #1

<p>'TO WHAT EXTENT CAN THE COST EFFECTS OF A DIVERSIFIED TECHNOLOGY BASE OPERATING UNDER TURBULENT CONDITIONS BE EFFECTIVELY MODELLED AND IF SO, WHAT ARE THE MAJOR ASPECTS OF DIVERSITY THAT ARE RESPONSIBLE FOR ANY INCREASE IN UTILITY.'</p>

It has been demonstrated that a simulation approach to modelling the technological and cost attributes of a diversified technology base is a feasible and useful assessment method for a limited class of problem. However, there are a number of methodological and technique related problems which diminish the effectiveness of

modelling diversification in this context. Specifically, difficulties associated with parameter representation and output interpretation constitute obstacles to effective modelling of diversified systems under turbulent conditions. The parameter representation problem concerns the identification of technological or cost attributes which may contribute to the utility associated with a diversified system. Output interpretation was made problematic by the phenomena of multiple solutions and difficulties with graphical surface generation techniques, although the latter of these was successfully resolved (See Appendix 1). The research thereby provides a positive but highly qualified answer to the first element of this research question.

With regard to what aspects of diversity can be associated with an increase in utility, the results which relate to this issue are moderated by the methodological problems outlined in the previous paragraph. However, the modelling activity did expose several relationships which are of interest in this respect. The utility of a diversified technology base was found to be sensitive to the following influences:

- a) The frequency and timing of substitution events between technologies.
- b) The length of use of each technology.
- c) The relative trends in cost profiles for different technologies.
- d) Ratio of technology capital to operating costs.

Perhaps the most influential finding related to the determinants of utility is that the systemic properties of a collection of technologies is of greater influence than individual plant or unit attributes.

A number of parameters which had a less than expected influence on the utility of a diversified technology base were also identified. These include lead time to build, plant scale and plant efficiency. The second element of the research question has thereby been investigated and several useful indicators of key sensitivities have been identified. However, the results are limited by the specific model configuration and general conclusions concerning the utility of diversified technology bases cannot be confidently advanced. Hence, the answer to the second element of this particular research question (composed of the sensitivities listed above), is tentative and constitutes a preliminary response. Additional (although not necessarily more complex or complicated), modelling work needs to be carried out before any significant contribution to this issue can be made.

It is pertinent at this point to review the comments made by Cole (1976), that were first introduced in Chapter 2 (§ 2.2.1). Whilst it could be charged that the modelling activities have much in common with the type of modelling work commented on in the sub-sections of Section 2.2, some important differences need to be established. Firstly, the modelling activities reported in Chapters 3 and 4 avoid many of the limitations of the use of stochastic techniques by focusing on the richness of the data generated and using all simulated event sequences as output. From one perspective this can be seen to contribute to the methodological problems encountered regarding multiple solutions and parameter representation. However, these issues are a direct result of the investigative technique and should not be overlooked.

Secondly, the model design process was informed by a desire to generate an exploratory tool. It should be remembered that there has been no attempt to develop any radically novel model structure or phenomena representation technique. The models were developed and used as investigatory tools to explore some concepts and relationships which have so far been omitted from published research on the subject of resilience.

10.2.2 Management in a turbulent environment.

Secondary research question #2

'WHAT MANAGEMENT PLANNING AND CONTROL STRATEGIES ARE ADOPTED BY MODELLERS AND MANAGERS OPERATING IN A TURBULENT ENVIRONMENT ?'

Management strategies under turbulent operating conditions were found to be characterised by flexibility. This attribute is considered important by decision makers and modellers alike, and is considered a major reason for the organisation being able to continue operations under turbulent conditions. The survey of management decision makers and modellers in Israel found that the flexibility referred to by respondents is characterised by a number of specific features. Firstly, formal information gathering and analysis processes play restricted roles in decision making. These processes are replaced by an emphasis on informal sources of information (trade journals, personal contacts etc) and more subjective evaluations of planning issues. Secondly, a distinct management style is evident, characterised by the promotion of flexibility, feasibility and consensus. Sources of flexibility are considered to be focused on the organisation's human resources. Consensus is encouraged both by negotiation and by high levels of investment in personal contact time with other managers and staff

As a caveat to these findings it was noted that the planning and control strategies adopted by Israeli management may promote survival rather than maximise profits or other benefits. Specifically, there is a more diverse range of objectives which Israeli Industry is concerned to address and this may account for the altered decision criteria. Hence, in response to the research question, the following strategy aspects can be posited as being characteristic of planning and control under turbulent operating conditions.

- a) An emphasis on flexibility (particularly as possessed by the organisation's human resources).
- b) An informal management style, characterised by an emphasis on personal contact..
- c) Restricted influence of formal analysis techniques.
- d) Changed criteria for decision making with the focus on feasibility and consensus.

10.2.3 The perceptions of O.R. practitioners.

Secondary research question #3

'TO WHAT EXTENT ARE O.R. PRACTITIONERS AWARE OF THE LIMITATIONS OF THE TECHNIQUES THEY USE, PARTICULARLY WITH REGARD TO UNCERTAINTY REPRESENTATION, AND HOW DO THEY VIEW THE BENEFIT OF THEIR ACTIVITIES TO THE ORGANISATION ?'

Data from the survey of O.R. practitioners confirm that O.R. professionals are well aware of the limitations of their techniques and are anxious to communicate these to other organisational actors. Their view of the benefits of O.R. to the organisation are focused on the rational / scientific approach which is fostered by O.R. techniques and they see the main danger from their use as being the misuse or misinterpretation of model output. This second point does however act as a constraint on the appreciation of O.R. limitations noted above. The rational / scientific approach which is considered to benefit the organisation is only one of several possible approaches to planning and control.

With regard to uncertainty representation, there was some ambiguous evidence concerning the willingness of practitioners to identify deficiencies in the techniques they utilise. Whilst nearly a third of respondents stated that they had no reservations whatsoever about utilising a particular technique, others (often referring to the same or similar techniques) listed several perceived problems. For those that did perceive problems, major sources of uncertainty were identified as being human centred or behavioural.

In response to the research question therefore, O.R. practitioners can be said to be generally aware of the limitations of their techniques within the context of the scientific approach which the techniques are derived from.

10.3 An interdisciplinary approach to assessing resilient technological systems.

Primary research question

'HOW CAN THE CHARACTERISTICS OF RESILIENT TECHNOLOGICAL SYSTEMS BE IDENTIFIED, ENGENDERED AND EFFECTIVELY MANAGED ?'

Chapter 1 included a discussion of the interdisciplinary nature of this work and identified the benefits of such an approach to research in general (§ 1.5). The three research activities have each provided a perspective on the primary research question, highlighting specific aspects of the core research issue and contributing a set of conclusions to the debate. The discussion presented in this section is intended to draw together the various themes and issues investigated through Chapters 2-9 so as to provide an integration of the information. Areas of conformity and conflict between the perspectives will be identified, thereby facilitating an assessment of the primary research question.

The interdisciplinary contribution of the thesis is focused on the use of more than one approach to problem analysis. Both the policy and methodological implications of the study reported in Chapters 8 and 9 respectively, draw on more than one element of the research. Where appropriate, reference has been made across disciplinary boundaries to highlight areas of conflict or compatibility between the research findings (e.g. § 9.3). Additionally, an assessment of the study's contribution to the primary research question will require a synthesis of the findings from each research activity to provide a comprehensive assessment of the problem area.. At the level of technique, both the modelling activity and the Israel survey used more than one technique for data collection. In the case of the modelling activity, computer programming, simulation, computer graphics, and econometric techniques were used. In the Israel survey both questionnaire and interview techniques were utilised.

The discussion of what constitutes interdisciplinary analysis provided in Chapter 1, stated that such appraisals are '*designed to both provide information on more than one aspect of a problem, and integrate the results in a way which assists policy and strategy analysis*'. Integrating the results of different perspectives involves identifying aspects of the problem where evidential findings enhance or contradict each other. The focal point for this discussion is the primary research question.

The primary research question contains three questions in one, with emphases on identifying, engendering and managing resilience in technological systems. The following sub-sections will address each issue in turn, collating information from the three research activities to provide a comprehensive discussion of each topic.

10.3.1 Identifying the characteristics of resilience.

Integrating the data from the modelling activities and the survey of management in Israel allows a number of conclusions to be made concerning the identification of resilience attributes. These comments concern both the nature of the attributes and the means for distinguishing them.

The modelling activities concentrated on diversity as an element of resilience. They were also exclusively concerned with cost and technology aspects of the system being analysed. Resultant from the simulation work, several key sensitivities were identified that influence the contribution of diversity to system performance. Additionally however, a number of non-trivial methodological problems were encountered which raise questions as to the effectiveness of modelling phenomena such as diversity and adaptability under turbulent operating conditions. The data from the Israel survey support the modelling work in this respect and provide complimentary evidence concerning the effectiveness of formal modelling activities under turbulent conditions. It was shown that organisations operating in turbulent conditions find that formal modelling and decision support techniques have a limited contribution to make to decision making. Furthermore, the dominant element of resilience under these conditions is focused on the flexibility of the organisation's human resources.

These results raise an issue of relevant emphasis for both organisations and researchers wishing to understand the dynamics of resilience. The modelling work showed that there is scope for developing strategies based on the maintenance of redundant capacity as a source of diversity. However, the Israel survey suggested that the human centred elements of flexibility are a pivotal aspect of planning and control under turbulent conditions. There is no evidence from the studies to suggest that an emphasis on hard (technology / cost) attributes or soft (human / organisational) attributes is relevant to any particular situation. Accordingly, it can only be speculated as to whether certain kinds of turbulence or certain types of operating environment are best addressed by certain aspects of resilience. This topic is taken up in Section 10.4 where emergent research issues are discussed.

The means for distinguishing aspects of resilience will be dependent upon the particular element being considered (diversity / flexibility; hard / soft etc). However, the Israel survey suggested that formal assessments of human resource flexibility are not engaged in, and that the determinants of the flexible attributes observed are socio-cultural in nature. This raises problems for organisations wishing to adopt such strategies and may partially explain the particular interpretation of labour flexibility that has been embraced in Europe and the USA (see § 8.3.2).

10.3.2 Engendering the characteristics of resilience

The problem of engendering aspects of resilience relates to the processes by which diversity or flexibility are to be instilled in the system of concern. The results of all three research activities contribute to a discussion of this issue, providing both practical and theoretical evidence for consideration.

The results of the modelling activities suggest that engendering diversity through redundant or spare capacity is a beneficial strategy under specific conditions. This allows diversity of cost profiles to be achieved at the cost of maintaining redundant plant ready to use (see § 3.3.1 for a description of cost profiles). Although modelling these aspects of resilience was shown to be feasible, engendering the desired attributes (e.g. an expanded and more diverse technology base) constitutes a separate process; one of change from one configuration to another.

A particularly significant aspect of engendering desirable system attributes is the process of change itself. From the modelling perspective, changes in system configuration were shown to be hazardous with regard to total cost performance (§ 3.4.2). Hence the process of diversity engenderment (a change from a single technology to a multiple technology base) should itself form a subject for analysis and planning. It should also be noted that change processes inevitably involve the organisational elements of the system such as personnel and organisational structure. The organisational actors who are most likely to be given the task of formulating and planning such change are the Operations Research or Management Science practitioners. Evidence from the survey of these professionals showed that their current techniques and skills may be better suited to handling the cost and technology related aspects of the change process than the human or soft elements.

The Israel survey did not provide any evidence of the change process discussed above. However, it did illustrate a situation where the principal determinant of flexibility (i.e. the major influence on the exhibition of flexibility as a trait), was a culturally and historically inherited approach to turbulence and uncertainty. Such inherited qualities are difficult to reproduce in different settings although their outward effects are capable of being synthesised in some circumstances. For example, the attribute which makes it possible for employees to fulfil more than one role can be instilled by expanding the training function to include issues of responsibility and inter-personal skills as well as task issues. Again, the O.R. community would need an expanded set of techniques to adequately tackle these issues.

10.3.3 Managing the characteristics of resilience

The final element of the primary research question pertains to issues of managing resilience. Once the attributes of resilience have been identified and engendered, there remains the problem of effectively managing them to ensure that resilience is achieved. However, the research conclusions raise the possibility that a revised form of management may be needed to ensure the best performance from a strategy which promotes resilience. It is proposed that the function of management is changed by an emphasis on attributes of resilience. Specifically, planning becomes a matter of attribute engenderment and control becomes the exploitation these attributes (diversity, flexibility, adaptability etc). The supporting arguments for this hypothesis are concerned with; a) the temporal aspects of strategies which promote resilience, and b) the nature of the strategy itself.

- a) The emphasis of this thesis on long term technology infrastructure planning (as outlined in Chapter 1) is not inconsequential with regard to the particular strategies being investigated. It has been demonstrated that a major influence on the utility of a diversified technology base (and thereby one designed to exhibit resilience) is the interaction between the system and environmental cost attributes. In order for diversity to be beneficial, opportunities must arise for the alternative items of plant to be used. Indeed, the very notion of resilience suggests the maintenance of some parameter over time. Hence, extended time scales are an integral element of strategies designed to promote resilience.
- b) A strategy which is designed to promote resilience over such extended time scales seeks to match possible changes in operating environment parameters with changes in system attributes. As described in Section 8.2.2, there is evidence to suggest that systemic properties are more influential than single unit properties as an influence on the level of match achievable. The focus of planning and control thereby needs to be focused on these systemic attributes, which will include organisational and human resource aspects as well as technology and cost aspects. The strategy is thereby ubiquitous and touches all aspects of the organisation's activities.

Strategies which promote resilience are therefore both long term in nature (i.e. they constitute 'the' strategy rather than one of many strategies), and they require a comprehensive approach to planning and control which includes all aspects of organisational activities. The planning role of management under these conditions is one of ensuring that the relevant aspects of resilience are engendered (whether in technological or human centred terms). The control function of management is then focused on managing the dynamics of resilience such as diversity exploitation and flexibility.

Two notes of caution need to be mentioned at this point. Firstly, it should be remembered that this is a somewhat simplified interpretation of the management role, there being a multitude of other criteria for consideration (such as environmental and product quality issues). However, within the confines of the types of industries which form the focus of this research, there is a case for subsuming (or at least attempting to integrate) many of these criteria within the need for resilience (see § 1.3). Secondly, strategies which promote resilience rely on the assumption that resilience is beneficial. Both the modelling activities and the Israel survey suggested that such benefits may be in the form of altered achievement sets focused on survival and stability.

10.4 Planning long term technological infrastructures; matching organisational attributes, organisational goals, analysis techniques, and levels of management sovereignty with strategic and decision issue context.

Having addressed each secondary research question (§ 10.2), the purpose of this section is to consider selected aspects of the research findings in the context of the core research issue. The discussion presented below integrates the management sovereignty and quality of information taxonomies discussed in Chapter 2 with the research results to generate some broader propositions concerning the long term planning of technological infrastructures.

Three conceptual tools should be reviewed at this stage in order to draw together the various aspects of the study and aid a discussion of the thesis' contribution. Figure 10.1 (repeated here from Chapter 1), illustrates the interfaces between the core policy issue and the three perspectives used as bases for the research activities. Figure 10.2 (repeated from Chapter 2), depicts the variations in approach adopted by the mechanistic and evolutionary problem solving methodologies. Finally, Figure 10.3 provides a conceptual framework within which to assess various aspects of the research conclusions.

Figure 10.1 Three perspectives on the core policy issue.

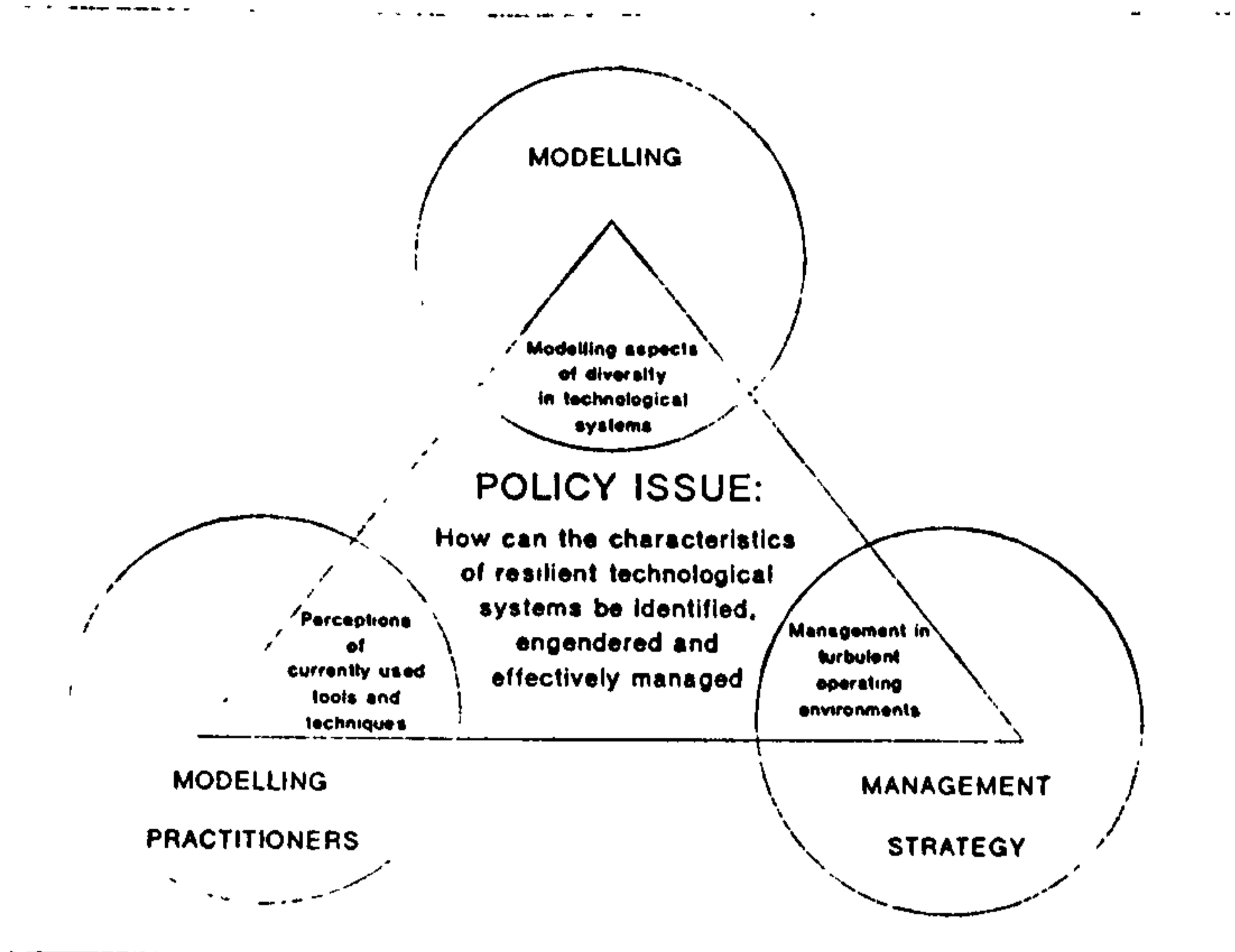
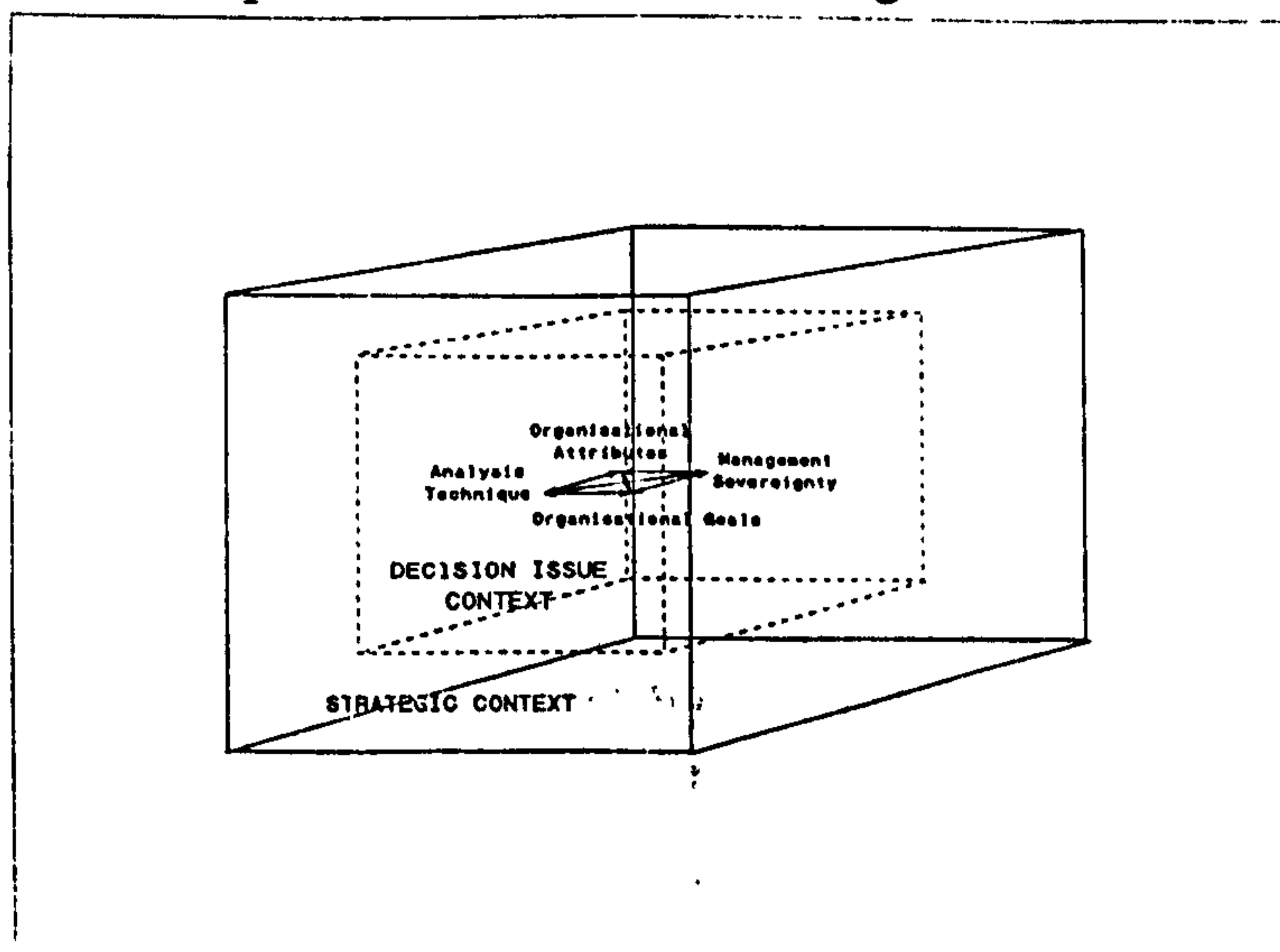


Figure 10.2 Comparison of problem solving approaches as determinants of emphasis in risk and uncertainty analysis.

PARAMETER ↓	MECHANISTIC APPROACH	EVOLUTIONARY APPROACH
VIEWS UNCERTAINTY	FAILING OR FAULT TO BE RESOLVED OR ELIMINATED	UNAVOIDABLE. INHERENT ELEMENT OF FUTURE
PRESCRIPTIVE PHILOSOPHY	PREDICT AND PREPARE	ADAPTIVE STRATEGIES. PROMOTION OF DIVERSITY LEARNING, EXPERIMENT AND CHANGE
FOCUS OF CONTROL	STATES	ATTRIBUTES
ANALYSIS TOOLS USED	REDUCTIONIST. CAUSE-EFFECT AND PREDICTIVE MODELS. OPTIMISATION TECHNIQUES	SIMULATION MODELS. EMPHASISES RELATIONSHIP BETWEEN AVERAGE AND NON AVERAGE FACTORS
CHARACTERISTIC MANAGEMENT STYLE	FORMAL. FORMALISED INFORMATION GATHERING	INFORMAL. EMPHASIS ON HUMAN CENTRED ATTRIBUTES

Figure 10.3 Conceptual framework for assessing the research conclusions.



As previewed in Section 1.4, the main message of this thesis concerns the development of a framework within which levels of management sovereignty, selection of analysis technique, organisational goals, and organisational attributes can be considered within a specific strategic and decision issue context. Figure 10.3 depicts this framework. The relevance of reproducing Figures 10.1 and 10.2 lie in their contribution in the areas of research process and theoretical development respectively. Figure 10.1 can be mapped onto Figure 10.3 to show how specific aspects of the core research issue (and subsequently the conceptual framework discussed below), have been researched. Figure 10.2 was utilised in Chapter 2 for the purpose of comparing the evolutionary and mechanistic approaches to problem solving. Within the context of the discussion below, it provides a template for a discussion of the interactions between different aspects of the planning and control process.

Figures 10.1 to 10.3 can be used to aid a discussion of the processes encountered during the research activities, in particular concerning the matching of system behaviour with appropriate analysis methods (see Section 10.5.3 below). Broadly, it is proposed that both decision issue and strategic contexts determine appropriate tools for analysis and options for action, and that the relevance of an evolutionary approach is strongly influenced by the parameters depicted in Figure 10.3.

With reference to Figure 10.3, a strategic context for any policy related query is provided by several features of the organisation's operating environment, the two most important with respect to this study being:

- The nature of key influences on the organisation's ability to operate (e.g. relative influence of financial, technological, political factors etc.)
- The level and nature of environmental turbulence.

The decision issue context is provided by the form of the query being considered, important aspects here including:

- The range of individuals or groups of individuals affected by the decision issue.
- The time scales associated with the decision under consideration.
- The level of complexity of the decision.

Within these two contexts, four sets of attributes can be identified that have been directly addressed by the research programme:

1. Management Sovereignty - Discussed in Section 2.6.2 and relating to the levels of control and influence which management has over the internal or external aspects of its operations. - Research components in Chapter 2.
2. Analysis Techniques. - Discussed in Section 2.2 and relating to formal or informal process of investigation and assessment relating to a problem or situation. - Research components in Chapters 3,4,5 and 7.

3. Organisational Goals. - Concerns the formal or informal objectives of the organisation. - Research components in Chapter 5.

4. Organisational Attributes. - Relates to the characteristics of the organisation (structure, management style, technological configuration etc.). - Research components in Chapters 3,4 and 5.

The following subsections show how the framework depicted in Figure 10.3 can be used to support a discussion of the relationships between these four attributes and the need to locate them within a specific decision issue and strategic context.

10.4.1 The role of strategic context and decision issue context in determining appropriate analysis and control tools.

The modelling activities described in Chapters 3 and 4 provide evidence for a number of non-trivial difficulties associated with modelling technology cost attributes under conditions of environmental turbulence. The preferred set of analysis tools recorded from the Israel survey reflected an alternative approach to plan and project assessment, emphasising human centred attributes and a less quantifiable set of parameters. These two findings demonstrate the importance of matching analysis technique with strategic context. The modelling activities suggest that the selected analysis technique (cost simulation) has only limited application as a tool for use in planning technology configurations under turbulent conditions. Given a greater degree of operating environment stability, the simulation modelling approach is likely to be of more use, as was noted from the O.R. practitioner survey where quantitative techniques were used with increased confidence. The nature of the operating environment in the Israeli setting has led to management adopting a revised set of analysis tools (albeit partially informal), with which to address issues of planning and control. This, despite the fact that the Management Science disciplines are well developed in Israeli academic and commercial environments.

The theme of decision issue context is not directly addressed in the research, but rather emerges from the research findings as a moderator of analysis tool and policy selection. For example, the survey of O.R. practitioners shows that the issue of the suitability of specific modelling techniques to specific problems is well appreciated and constitutes an important focus of concern amongst Management Science professionals. This finding suggests that where a specific technique has been utilised, model output needs to be considered in the context of the decision issue. Further evidence for this view comes from the Israel survey where an altered, more wide ranging, set of organisational goals is apparent. The resultant decision issues are thereby subtly modified to reflect changes in the desired aims of the organisation, resulting in a changed set of analysis and control tools dominating the management function.

10.4.2 Achieving a balance between organisational attributes, organisational goals, analysis techniques and management sovereignty.

Within the decision issue and strategic contexts of a policy query, four attributes have been identified (see § 10.4 above), that reflect aspects of the planning and control function. Each of these properties have been commented upon in isolation at various points in the preceding text. However, Figure 10.3 depicts them as interacting and it is these associations which are of interest within the conceptual framework being discussed here. The capitalised statements found below are prescriptive in nature and are proffered as normative reflections on the research findings. No hierarchy of influences should be imposed on this somewhat complex set of relationships and the desired status of the framework is one of balance rather than maximising the influence of any single element. The following statements and supporting explanations (the latter derived from the research findings), characterise the core relationships between the four parameters that form the title of this sub-section.

- **AN AWARENESS OF THE EXTENT OF MANAGEMENT SOVEREIGNTY IS DESIRABLE BEFORE APPROPRIATE ORGANISATIONAL ATTRIBUTES CAN BE REALISTICALLY SELECTED AND ENGENDERED. HOWEVER, CERTAIN ORGANISATIONAL ATTRIBUTES WILL ALSO INFLUENCE LEVELS OF MANAGEMENT SOVEREIGNTY.**

The study of modellers and decision makers in Israel exposed a situation where the high levels of environmental turbulence bounded management sovereignty relatively strongly. An awareness of this on behalf of management leads to a move away from planning and engendering organisational attributes which require high levels of control. This matching of control potential with organisational characteristics reflects an emphasis on the feasible over the desirable and, as will be seen below, also has an influence on the selection of analysis techniques. The modelling activities provide an additional point of reference for this statement by highlighting the pitfalls involved in modelling technological system performance without any knowledge of how changes to alternative configurations are to be achieved. This led to some of the model output being of limited use as the practicalities of system manipulation had to be assumed.

As outlined in Figure 10.2, one of the characteristics of an evolutionary approach to problem solving is a shift of emphasis away from controlling states towards controlling attributes. This trend is observable in the Israel context where forecasting plays a limited role in the planning function and sources of flexibility are focused on human centred attributes. Hence, a linkage is discernable between strategic context (stable / turbulent), levels of management sovereignty (control / impotence), and the focus of management control (states / attributes).

The second part of this statement reflects the fact that levels and modes of management sovereignty (i.e. the strength and type of control achievable), will partly be a reflection of certain organisational attributes. Typical of this situation is the manner in which the characteristics of management structure result in variations in the level of control available over different aspects of the organisations activities.

- **THE NATURE OF ORGANISATIONAL GOALS IS A KEY INFLUENCE ON THE SELECTION OF BOTH DESIRABLE ORGANISATIONAL ATTRIBUTES AND THE DEVELOPMENT OF SUITABLE ANALYSIS TECHNIQUES.**

The modelling activities reported in Chapters 3 and 4 were initially based on a specific system goal (that of achieving low total costs over extended time periods). Under these conditions, the benefit of the diversified technology base over a single technology one was marginal. However, in the later stages of the modelling activities, these goals were modified to include criteria such as cost stability. Under these revised system goals, the diversified system was more successful thereby demonstrating the link between organisational goals and relevant system attributes. Another example of the relationship between organisational goals and organisational attributes can be gleaned from the dependence of the diversified system's utility on extended time horizons. Here, the association of increased benefits with prolonged system operation restricts benefit to those organisations willing to take a longer term view of their operations.

As was seen in the Israel survey, the approach to handling turbulent operating conditions is associated with a revised set of organisational goals based on issues of survival. Consequently, the nature of the analysis tools utilised was also altered. Here, optimisation and quantification were often passed over in favour of more informal modes of analysis, often reflecting issues of consensus and achievability. Here again the emphasis on attributes (here represented by organisational goals focused on survival) rather than states is evident within a specific strategic context.

- **ORGANISATIONAL GOALS AND LEVELS OF MANAGEMENT SOVEREIGNTY SHOULD BE MATCHED SO THAT THE FORMER ARE NOT IMPRACTICAL DUE TO THE LIMITATIONS OF THE LATTER.**

Without a clear appreciation of the nature and extent of management influence over organisational and external factors, realistic organisational goals cannot be determined. Whilst there is no evidence in the Israel survey to suggest a link between the limits to management influence and the adoption of an alternative set of organisational goals, the association of the two phenomena within the context of operating environment turbulence fits well inside the framework depicted in Figure 10.3.

- **SELECTED ANALYSIS TECHNIQUES NEED TO TAKE ACCOUNT OF LEVELS OF MANAGEMENT SOVEREIGNTY SO AS TO AVOID A SITUATION WHERE THE ANALYSIS TECHNIQUE ASSESSES MODES OF MANAGEMENT ACTION WHICH ARE UNATTAINABLE.**

Utilising analysis techniques which assess processes or states which are unattainable due to the limitations of management sovereignty is obviously undesirable. This issue is well reflected in the survey of O.R. practitioners. Here, reservations about the application of analysis results were communicated to other organisational actors in an attempt to restrain their utilisation outside the bounds of the analysis' assumptions. A

key focus for such concern is the inclusion of human or 'soft' elements whose behaviour cannot be readily modelled. Furthermore, management control over such elements is often only partial or incomplete, making the use of many modelling and analysis techniques inappropriate.

- **THE SELECTION OF APPROPRIATE ANALYSIS TECHNIQUES NEEDS TO BE INFORMED BY BOTH CURRENT AND DESIRED ORGANISATIONAL ATTRIBUTES.**

This statement encapsulates the main thrust of the research activities' findings. In the case of the modelling activities, despite generating some useful policy related data, several methodological bounds to investigating issues of technology cost diversity under turbulent operating conditions were identified. The organisational attributes which were desired (those of diversity and flexibility), whilst being representable in a manner suited to quantitative modelling, are perhaps best captured (in the relative strategic and decision issue contexts) by other types of analysis. This point was accentuated during the Israel survey where quantitative modelling was seen to be of less importance than other, more human centred, modes of assessment. The following subsection takes this relationship and expounds its importance within the wider framework of Figure 10.3, using examples from the research findings where relevant.

10.4.3 Selecting organisational tools and attributes within a strategic context.

As a mechanism for demonstrating the concepts and relationships discussed above, this subsection sets some of the research findings within a strategic context and discusses the selection of pertinent analysis tools.

One possible factor which could be used as an indicator of strategic context is the quality of information available concerning the organisation's operations and its operating environment (hereafter referred to as system attributes). A taxonomy of information quality was introduced in Section 2.6.2, relating to the reliability of observed behaviour, forecast trends etc. The taxonomy's major classes are Certitude - Knowledge - Ignorance.

Where system attributes and dynamics are known with certitude, quantitative modelling can be seen to contribute towards effective planning and management. However, two types of system change are particularly difficult to capture in formal quantitative models.

1. Changes in quantitative measures of parameter or system state which fall outside expected bounds.
2. Qualitative changes in system configuration or the introduction of novel system elements.

Where these types of changes dominate system behaviour, increases in both ignorance of system behaviour and impotence to control such behaviour are reflected. The

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Where these types of changes dominate system behaviour, increases in both ignorance of system behaviour and impotence to control such behaviour are reflected. The

modelling activities reported in Chapters 3 and 4 attempted to expand the scope of formal models to address problems associated with ignorance and impotence by using concepts of resilience and diversity. However, the modelling activities and the Israel study suggest that there are limitations to the role of quantitative models in providing useful input to assessments of resilience and diversity. Furthermore, O.R. practitioners are aware of the limitations of quantitative models as they have been shown to recognize the boundaries of model application.

Situations associated with certitude can therefore be analysed with confidence by the use of predictive simulation models. However, as the quality of information becomes less certain, the less confident organisations can be in the results of such models (as demonstrated by the modelling activities reported in Chapters 3 and 4). Hence, other methods of planning and control need to be adopted. A reliance on the organisation's human resources as a source of flexibility in these circumstances has been shown to be one possible strategy under turbulent conditions.

For example, the operating environment faced by Israeli managers can be identified as reflecting high degrees of ignorance. Israeli managers indicated that they are concerned mainly about aspects of their operating environment which they are impotent to affect. Furthermore, the paucity of attempts to forecast operating environment parameters suggests that there are severe bounds to carrying out formal analyses of such parameters. Under these circumstances, the focus of flexibility was found to be on the organisation's human resources.

The survey of O.R. practitioners found evidence that the O.R. community appreciates the difficulties involved in applying formal assessment techniques to problems which include aspects of 'ignorance' or 'impotence'. Indeed, the development of 'soft' and 'complex' systems theories are direct attempts to address this problem. Recent theoretical developments in the fields of modelling and Management Science are engaged in a process of expanding the application of formal quantitative modelling to encompass a widening range of applications.

Hence, environments which are characterised by turbulence which can both be predicted and whose main attributes lend themselves to quantitative representation, can be addressed by 'harder' aspects of resilience such as diversity of technologies or products. Alternatively, environments where turbulence is unpredictable and not quantifiable may require a different approach to resilience focused on human resource attributes. This general (and deliberately tentative) approach to managing resilience can be extended by considering two aspects of the research results that demonstrate a 'hard' and 'soft' perspective respectively.

1. The finding that there are limits to the conditions under which diversity (as characterised by redundancy) can be beneficial is potentially useful in a policy context. In particular, operating environments which do not provide opportunities for technology or other factor substitution do not call for diversity to be used as a strategy tool. Thus, turbulent operating environments and strategies based on resiliency need to be matched in order for any benefits to emerge. Those features of the environment which are unstable need to be matched with elements of the system which can react

positively to such change, thereby aiding resilience. The results from the 'LTIME' model illustrate this point as the diversity of cost elements was only a partially successful response to the cost turbulence of the operating environment. A greater degree of flexibility could have been achieved by matching the diversity of technology cost elements even more closely with the cost changes being experienced in the operating environment.

2. A further general point of use in a practitioner context is the relative emphasis put on human resources as providers of adaptivity under turbulent operating conditions. The study reported here provides some support for Friend & Hickling's (1987) conclusions and exposed evidence that adaptiveness resides in attitude and willingness to change as much as in ability to change. Friend and Hickling stated that organisations should '*learn to work with uncertainty*'. The research findings suggest that there should be an emphasis on generating and promoting the 'ability to learn' so as to enhance the potential of the organisation to adapt. Diversity of approach and versatility of skills may therefore be less significant than the possession of attitudinal characteristics which are predisposed to change.

10.5 Implications of the thesis' findings for future research.

Research issues emergent from the work reported above could be identified from the three research activities themselves, each of which highlighted a number of areas for future work. However, in keeping with the interdisciplinary approach fostered in the preceding chapters it is more relevant to derive an emergent research agenda from the policy level issues. The broad aims of future research in this field should be on both exposing the nature and strength of relationships between the various aspects of resilience, and on the development of practical analysis tools for use in strategic planning. The following five issues constitute those areas where it is considered that additional inquiry may yield worthwhile results.

1. There is a tangible distinction to be drawn in the research conclusions between the hard and soft aspects of resilience. A desirable avenue for further research is therefore concerned with the identification of the contribution of each aspect towards resilience in different types of system and under different conditions. Such research should include an investigation of the relationships between the various elements of resilience depicted in Figure 2.3. In particular, the interaction between different sources of turbulence and the determinants of resilience appear to warrant further research. For example, can turbulence thresholds be identified above which resilience (or specific types of resilience) becomes a beneficial strategy? or, can levels of diversity, flexibility etc be matched with varying levels of turbulence? Further work on this issue should take note of the work of Woodward (1982) and Wholey & Brittain (1989) who warn against uncritical or narrowly defined notions of turbulence.

2. As a related issue, there is a need for research on the feasibility of combining an assessment of the soft and hard aspects of resilience. There are several examples of non-numerical models available, suggesting that alternative modelling approaches can be developed to study the behavioural aspects of various strategic issues. These

include the human problem solving model (Newell & Simon, 1972), and the belief system model (Carbonell, 1979). The development of policies focused on issues of resilience provides an opportunity for alternative types of model to be developed. Research should thereby concentrate on generating useful interdisciplinary models which allow the integration of quantitative and qualitative contributions.

3. The relative importance of systemic attributes over individual plant attributes as positive influences on the utility of a diversified technology base is also an important area for future research. Again, the hierarchical aspects of resilience and the influence of diversity and flexibility at different systemic levels constitutes a complementary area of study. Diversity of cost elements was found to be ineffective without the potential for change between them (flexibility). Likewise, the ability to change (adaptability) was needed in order to execute the potential for change. The relationships between the elements of resilience were only covered superficially in the modelling activity. However, the results suggest that this is one area where the use of formal quantitative models may be of benefit by investigating the systemic properties of resilient technological configurations.

It is particularly important for further work to be carried out on formalising the structure of these hierarchical elements and developing an appropriate language for describing their main features. For example, diversity, flexibility and adaptivity are reflected in different elements of a technology. Hence, models should be able to capture the pertinent sources of diversity etc. for each technology or group of technologies. Furthermore, effective, generalizable ways of measuring diversity need to be developed in order for a generic model type to be possible. It is not clear whether such a generic technology planning model based on issues of resilience is achievable and further research is needed to test the robustness of the concepts used. The limits to the use of biological analogies and the associated terminology should also be addressed and any limitations clearly outlined.

4. It is clear from the research conclusions that strategies which emphasise resilience cannot be developed by the use of a single type of technique. Both qualitative and quantitative aspects need to be assessed, as does the relationship between them. It is therefore important that the process of decision support in this area be better understood. The role and limits of formal modelling need to be addressed, and the internal organisational dynamics which relates modelling to decision making requires further research. Concomitant with such a study, there is scope for additional research on the perceptions of model role by both modellers and decision makers (possibly including the retrospective sense-making identified by Aronson, 1976).

5. Finally, the bounds of the modelling activities reported in Chapters 3 and 4 need to be stretched so as to extend the applicability of the model output. As noted at several points in this thesis, the modelling activity addresses a restricted set of sub-issues with regard to the benefits of diversity on total system costs and cost stability. Different classes of problem need to be tackled, concentrating on other types of diversity and a more comprehensive representation of technology attributes, in order to enhance the usefulness of the modelling approach. A case study approach would be useful in this

context, allowing a more accurate model configuration and providing some operational time series data with which to correlate model output.

10.6 Summary of thesis contribution.

In summary, the contribution of this thesis lies in the following points:

1. The novelty of an interdisciplinary approach to problems of planning long term technological infrastructures.
2. The identification of technology configurations and cost conditions under which a diversified technology base exhibits utility over a single technology system.
3. Description of some methodological limitations to modelling diversity through redundancy under turbulent cost conditions.
4. Identification of key elements of management planning and control strategies found under turbulent operating conditions.
5. Assessment of the perceptions of Operational Research professionals towards the tools and techniques they utilise.
6. An analysis of the above points in the context of policy development and methodology, providing an integrated assessment of the use of resilience as a tool for planning long term technological infrastructures.
7. Development of a conceptual framework within which to discuss the matching of organisational attributes, organisational goals, management sovereignty and selection of analysis techniques within appropriate decision issue and strategic specific contexts.

It is important to note that the use of concepts of resilience and its associated elements is neither radical nor particularly novel. Both Milliken (1987) and Allaire & Firsirotu (1989), identified the predict and prepare philosophy as suspect and proposed flexibility as at least one element of an alternative approach to strategic planning. A more structured alternative to the predict and prepare methodology together with a design for a "*responsive decision system capable of rapid and effective learning and adaptation*" can be found in Ackoff (1983). Whilst such a blueprint is pertinent to the above discussion, Ackoff's prescriptive tack is too formal and inflexible to attract support from the evidence exposed in this thesis. Concepts of resilience have also been addressed by Holling (1987) in the context of natural systems. Other authors have investigated the issue of flexibility as a tool to combat uncertainty (Rosenhead et al 1972) whilst still others have developed ideas of adaptiveness and diversity in other fields such as Organisation Theory, (Beer, 1966), Complex Ecological Systems (Allen, 1992; Walters, 1986), Economics (Nelson & Winter, 1982), and Development Planning (Sachdeva, 1984).

The research reported in the foregoing chapters is both informed by the work of these authors, and provides a limited contribution to what is a developing and expanding area of research into concepts of resilience. As a strategy, identifying applicable sources of resilience and engendering the organisation with the characteristics discussed above requires preparation and evaluation. Queries concerning the type of characteristic desired and the level and form of attributes require careful analysis. What has been exposed in this thesis is that the class of models typified by those developed in Chapters 3 and 4 has limited scope in being able to generate applicable information. What appear to be of greater benefit are human and organisationally focused elements which serve to provide diversity and flexibility of attitude, behaviour and thought. Such elements are associated with alternative goals centred on concepts of survival. Furthermore, appropriate tools for analysing human and organisational flexibility need to be located within an approach which is wider than that currently exhibited by Management Science practitioners. The potential for enhancing the O.R. approach with contributions from the social sciences has recently been highlighted by Jackson (1993). Evidence from the research programme reported above suggests that, within the context of planning and managing resilience, the introduction of social science elements would improve the range of appropriate tools available. The study contained in this thesis also supports the view that understanding the determinants of method and the context of problem and method, lead to new insights into the matching of analysis method and policy issue. Or, as Jackson phrases it:

"The understanding of the presuppositions of different operational research methodologies made possible by social theory can help with the important question facing 'enhanced' OR practitioners, of which methodology when?"

In summary, policy issues often embrace several types of problem, each of which may be best addressed from a discipline specific perspective. What has been demonstrated in this study is that by exposing the interfaces between the policy issue and each discipline specific contribution, a more robust assessment of the core issue can be developed. In the example presented in this thesis, the contribution has been to identify some methodological boundaries to the use of certain analysis techniques, and to suggest a framework for conceptualising the linkages between various elements of the policy issue.

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APPENDIX 1

Appendix 1 provides supporting information for the modelling activities reported in Chapters 3 and 4 of the main thesis. The following pages provide details of the computer models used to generate the output shown in these chapters, and include discussions of the surface generation problems encountered, and the cost function generation algorithm used for both the DIVERS(X) and LTIME models.

Base Case Parameters For LTIME Model (Chapter 4)

The following figures show details of the input parameters used as the base case for the model described in Chapter 4 (LTIME). Figure A1-1 illustrates the capital and operating cost profiles for each technology. Figure A1-2 shows the scale function used to adjust capital costs for differences in plant size and Figure A1-3 shows the function which represents changes in capital cost dependent upon design life variations.

Figure A1-1

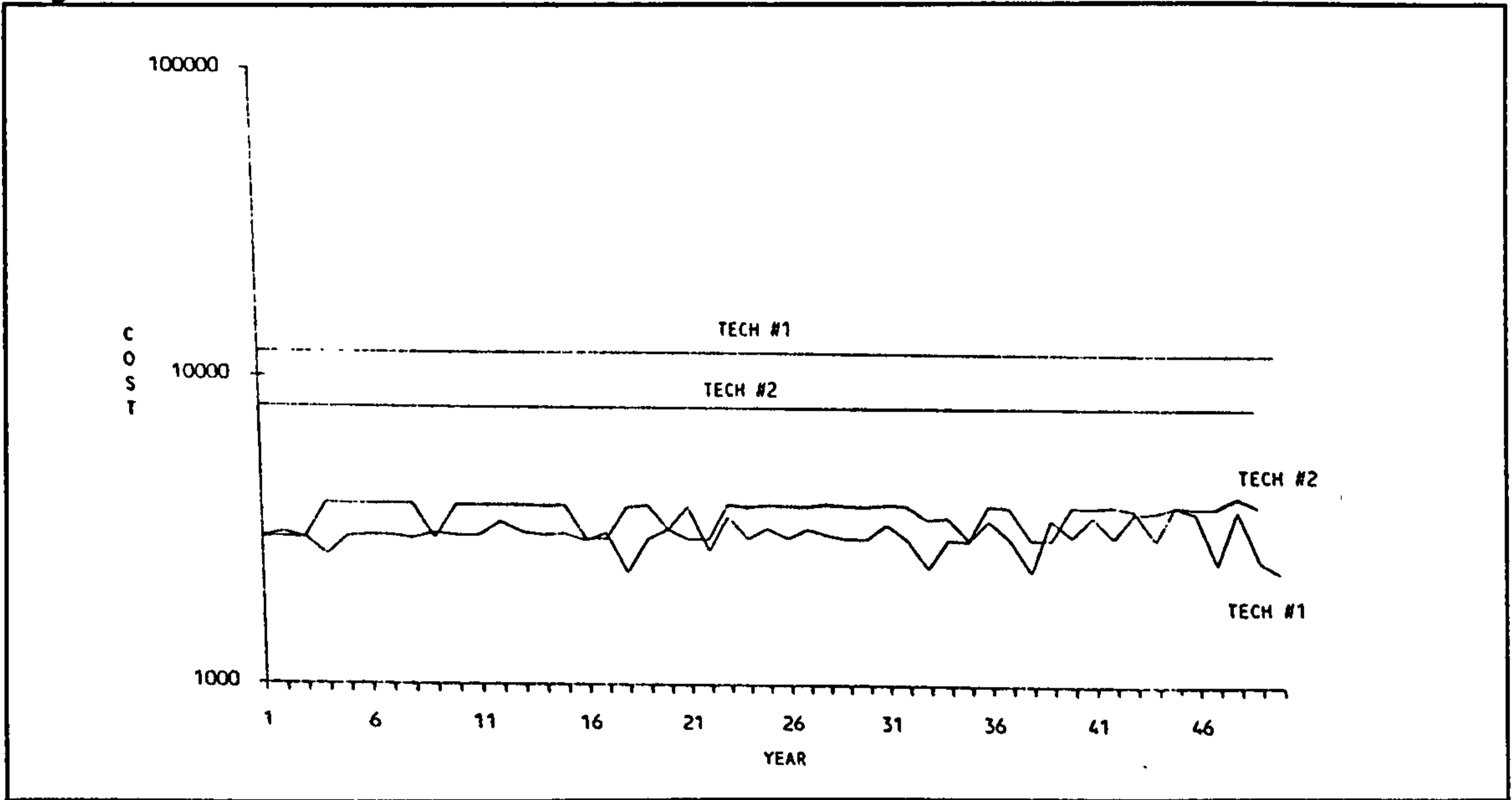


Figure A1-2

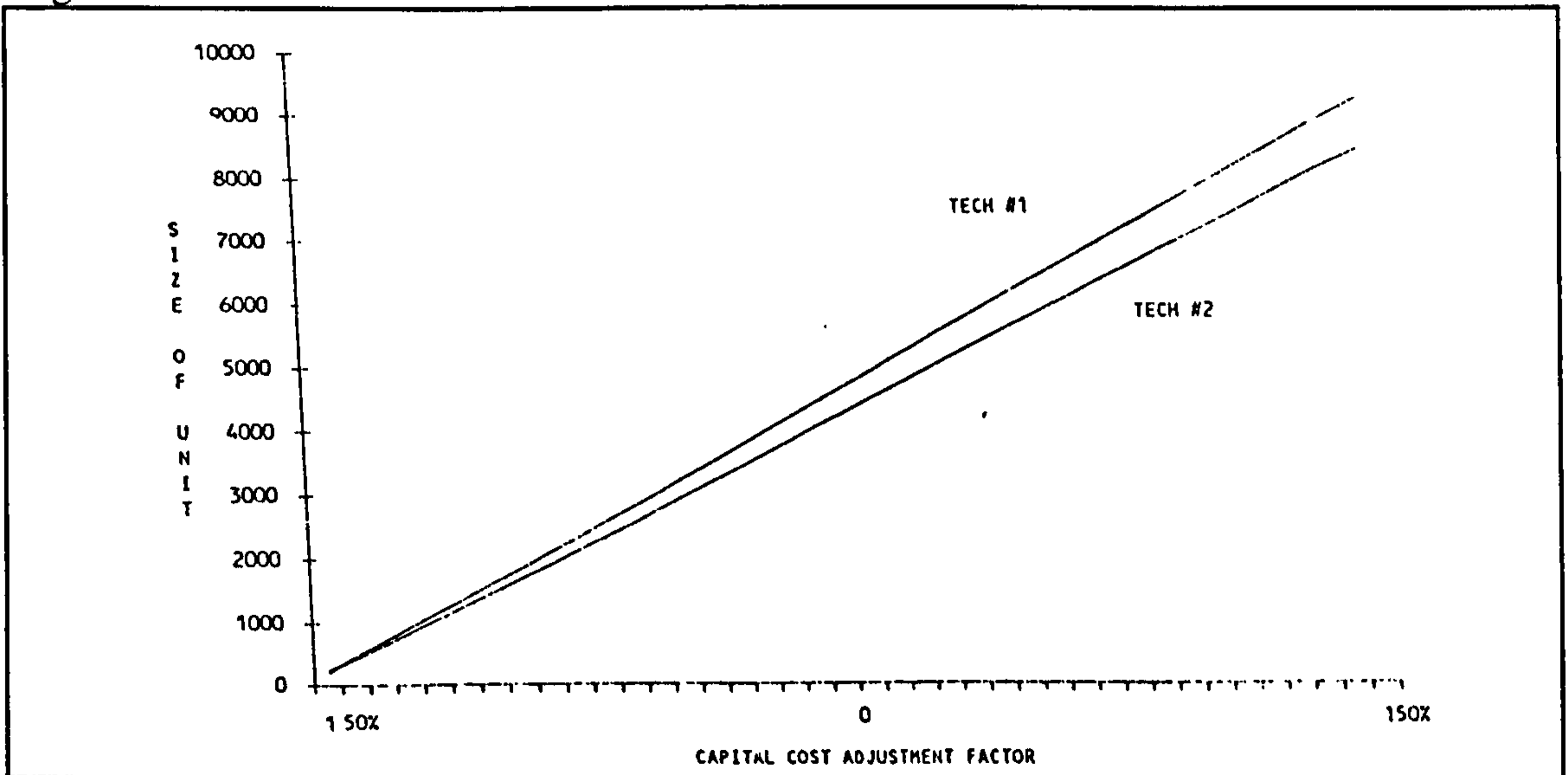


Figure A1-3

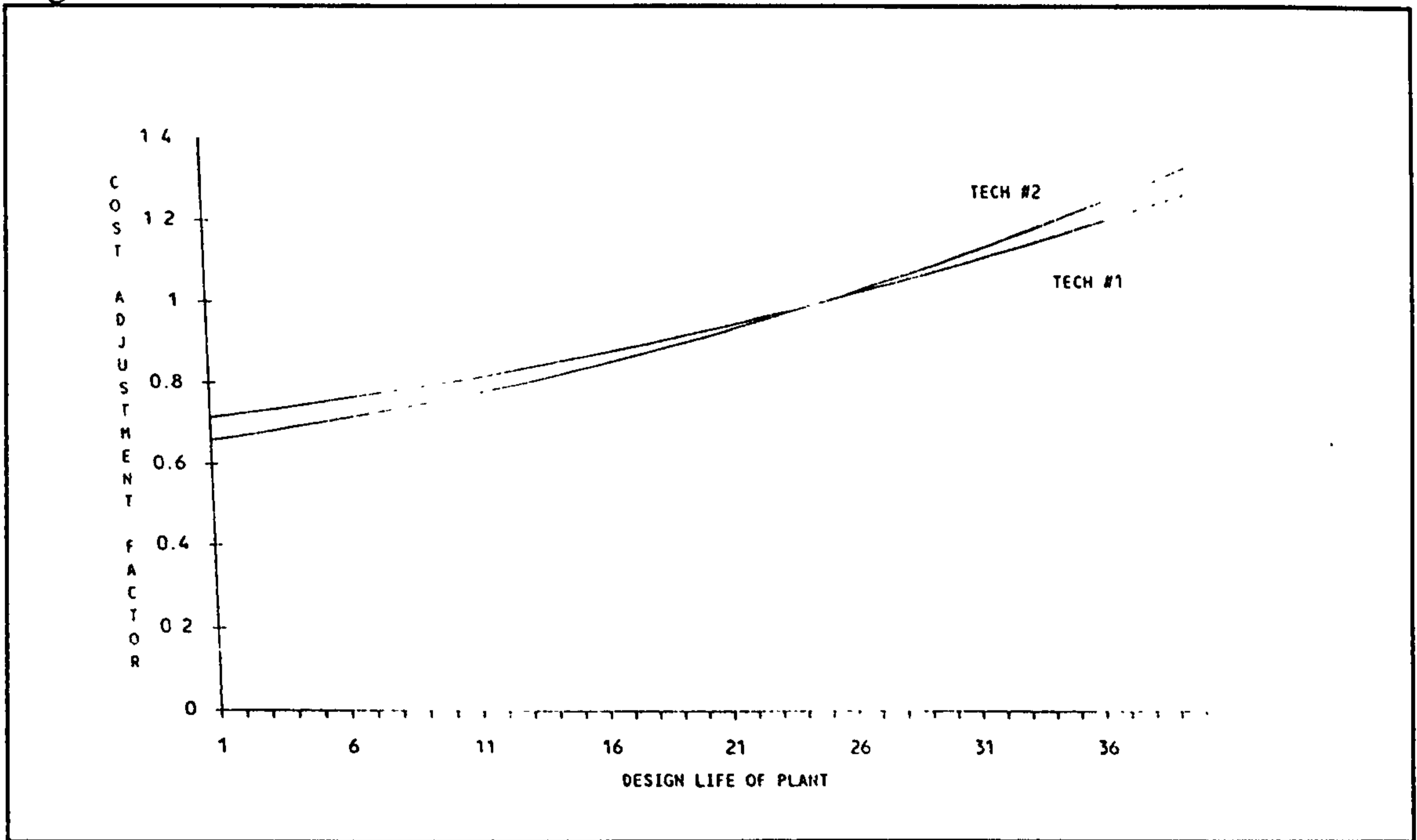


Figure A1-4 a and b, illustrate the functions applied to the operating costs for each technology, allowing differences in age, years of operation, unit size, and intensity of use to be allowed for in the final costings.

Figure A1-4a

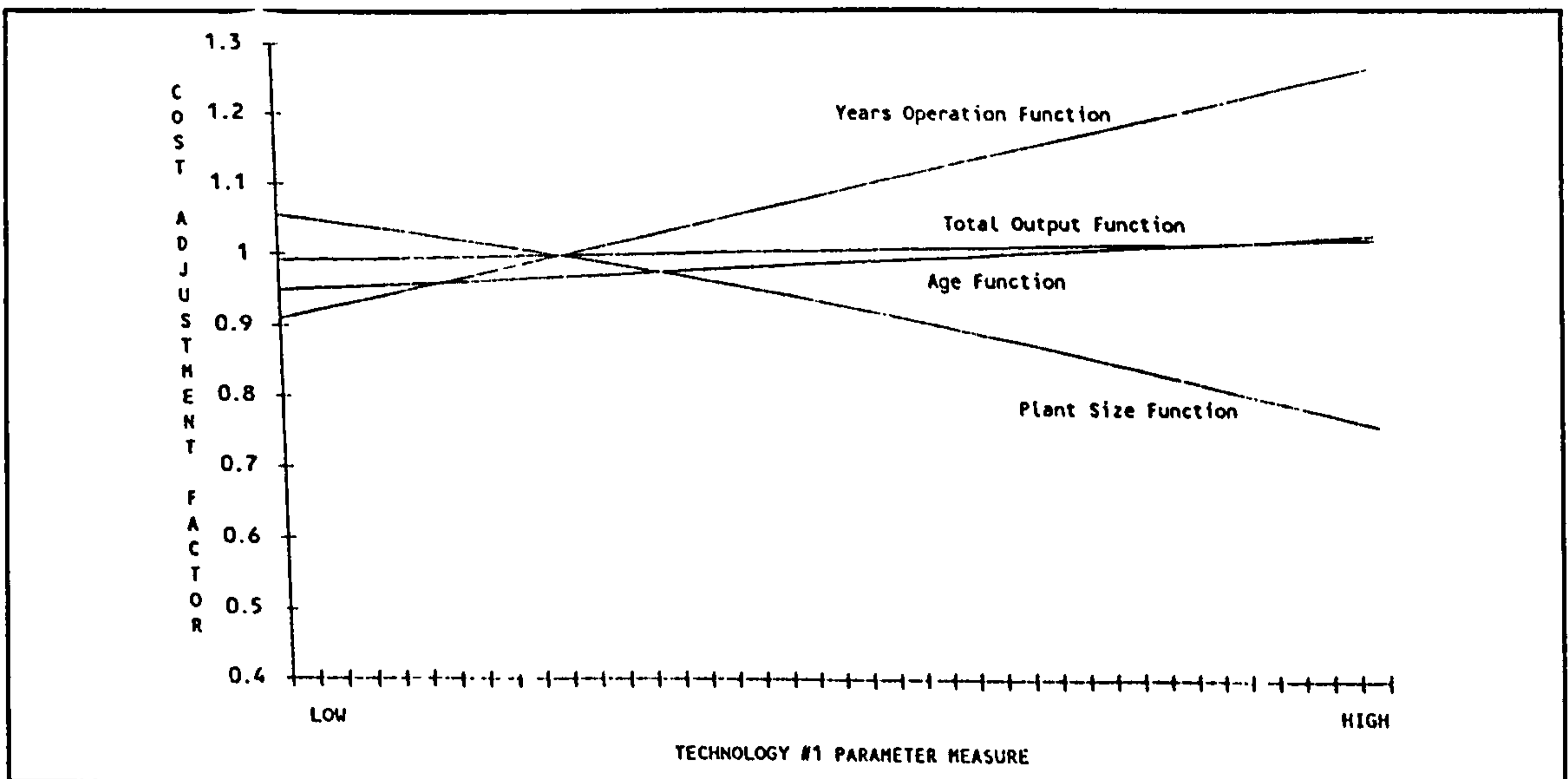
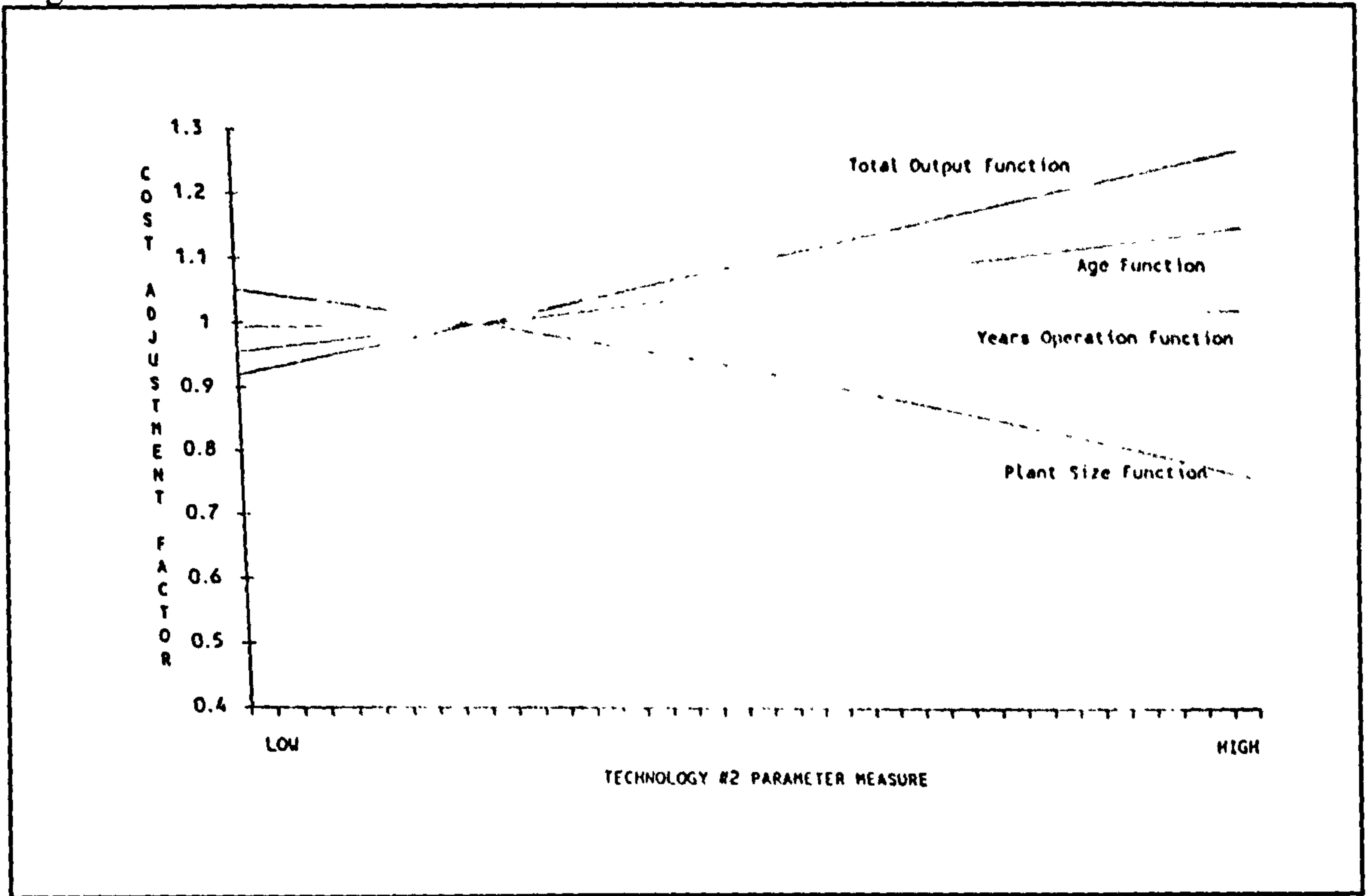


Figure A1-4b



Generation of the functions to represent capital and operating costs and demand levels in 'DIVERS(X)' & 'LTIME' programs

The technique used to generate these values is based on a combined stochastic / deterministic algorithm which utilises bounded random numbers to achieve a level of control over the temporal development of each function. In detail, this consists of initially describing a cubic function with the constant values replaced by variables. This produces a generic term of the form:

$$ax^3 + bx^2 + cx + y$$

where: a,b,c, and y are all variables and x is a temporal factor representing the year in which the function is being assessed.

Each cost element (capital, operating, maintenance, dormancy etc.) for each technology type is then identified with a unique function and minimum and maximum bounds for each sub variable (a,b etc.) are predefined. (Note: the maximum and minimum values can be identical thereby allowing complete determinism). In addition to the basic function form, there are a number of a secondary variables which act as 'control factors' on function development. These are listed below with a description of their relevant effects.

Macro turbulence (MT): Influences the sign of the selected function. Acts to induce macro turbulence by alternating the general trend of the function, either increasing or decreasing the value of the function over extended time periods. The factor itself is entered as a value between 0 and 1. A random number is then compared with the product of the factor and the random number maximum limit. An 'if' statement then determines which type of equation (positive or negative trend) to access.

Frequency of Turbulence (FT): Executes a similar role to the macro turbulence, but on over shorter time scales. Invoked subsequent to macro turbulence test and utilised in a similar way, the result of the 'if' statement determines whether a cubic or quadratic form of the equation will be used.

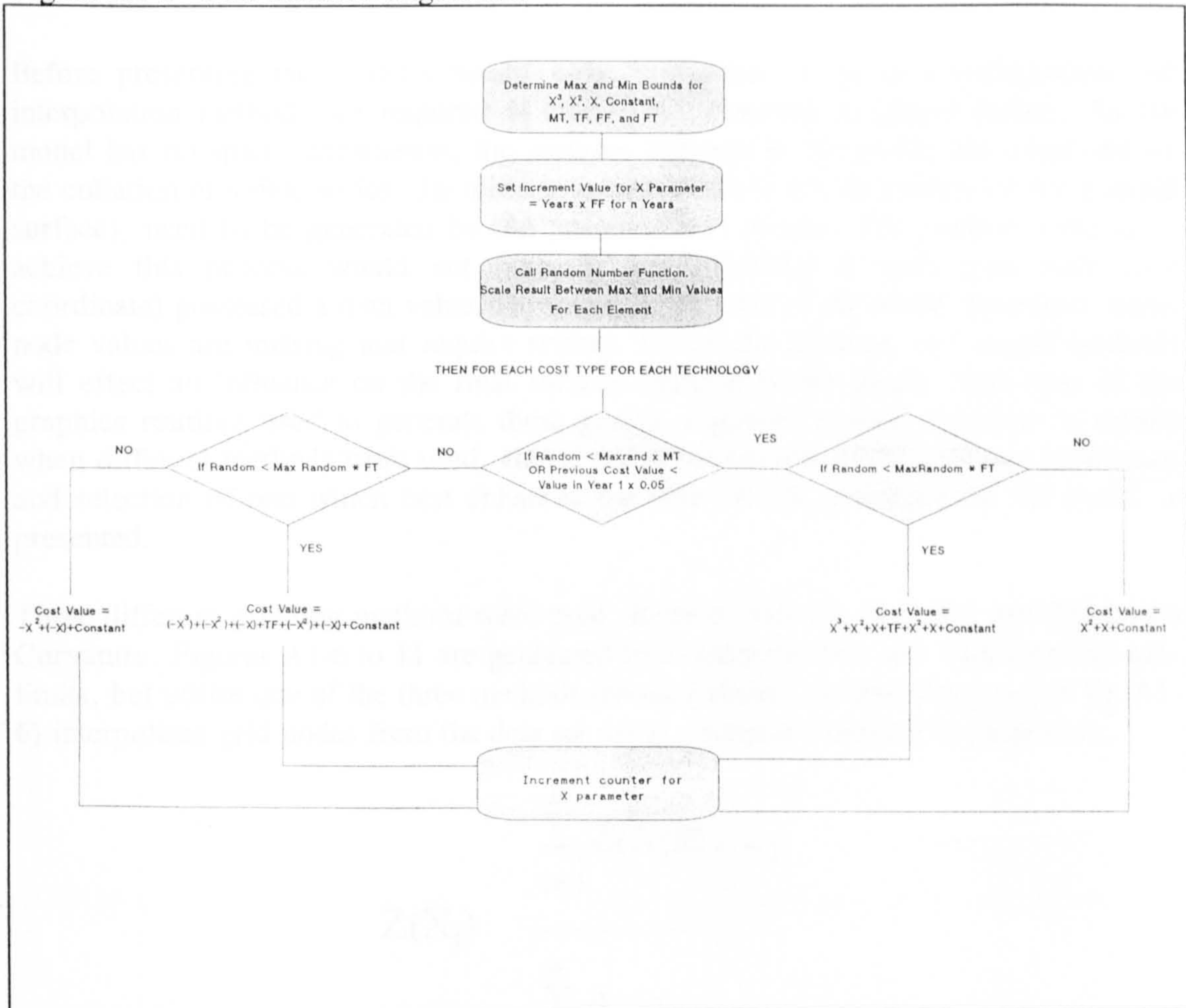
Turbulence Factor (TF): Entered as a value range which determines the magnitude and sign of shorter time scale turbulence. (i.e. the movements about the mean value).

Frequency Factor (FF): This variable is used to determine the time step intervals applied to each simulation run. Although the number of years in each run will be fixed, the Frequency Factor allows different rates of change to be developed in the cost functions, independent of the yearly intervals.

It should be noted that each technology's function set (capital, operating etc.) can possess differing values of each of these factors, and that the values can also vary across technologies. Indeed, this is one of the major benefits of this calculation procedure, allowing a variety of cost trends to be broadly described and controlled.

The algorithm which determines the application of each of the above described elements of the cost function is given below:

Figure A1-5 Cost function Algorithm.



In addition to this algorithm, the cost generation sub-program allows a switch to a new magnitudinal level to be simulated for any cost element. This is achieved by allocating a time of switch, determining which year the switch is made in; and a factor of switch, establishing the extent of the switch. This has the combined effect of moving the average trend of the cost function either up or down, thereby creating a new cost 'regime'.

As mentioned in the main text, manipulating the variables which contribute to the cost function trends takes some cultivating. In particular, maintaining the bounds of the cubic term becomes problematic under some conditions as the positively and negatively signed elements diverge, producing wild fluctuations in the function. Desired levels of randomness (pseudo?) within the bounds of the maximum and minimum values determined, in conjuncture with the regime switch mechanism provides a powerful tool for the simulation of cost environments for one or multiple technologies.

Surface generation techniques

Before presenting the model's results some discussion of the data presentation and interpolation methods are required to clarify the presented graphical output. As the model has no spatial parameters, the surfaces depicted in the results are generated by the collation of a data series, the missing values of which (in the context of the gridded surface), need to be generated by the presentation software. The method selected to achieve this process would not normally be influential if each grid node (x,y coordinate) possessed a data value. However, in the case of the model presented, some node values are missing and require setting. Hence the gridding and search methods will effect an influence on the final surface depicted in the graph. Test runs of the graphics routines used to generate these graphs suggested a wide variation of results when different methods were used. Hence a brief discussion of the relevant techniques and selection of one which best enhances the type of data generated by the model is presented.

Three different gridding methods were used. Inverse Distance, Kriging, and Minimum Curvature. Figures A1-6 to 11 are generated from identical data sets with identical axis limits, but utilise one of the three methods itemised above. Inverse distance (ref fig A1-6) interpolates grid nodes from the data set using a weighted moving average thus:

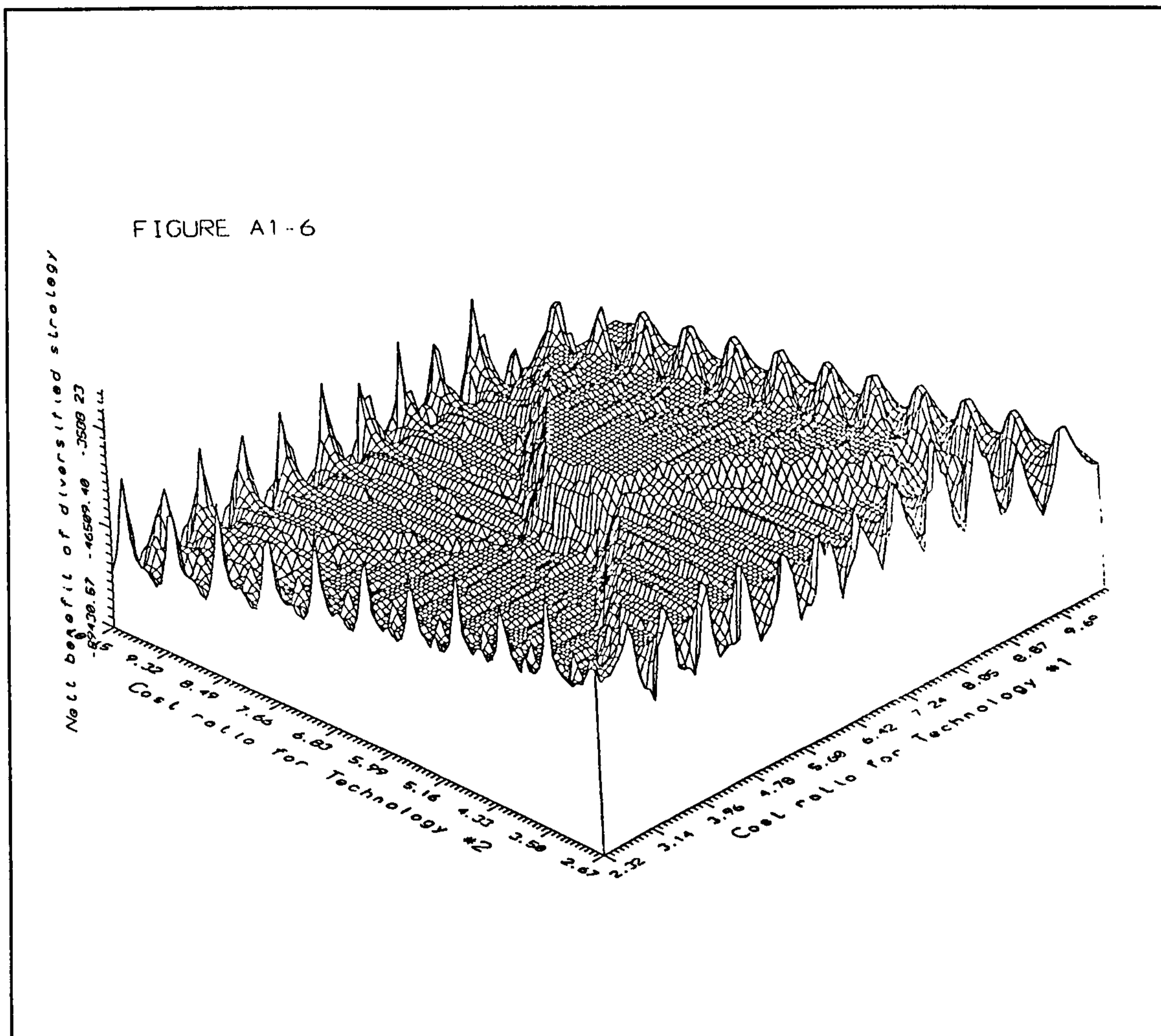
$$Z(X_j) = \frac{\sum_{i=1}^n Z(X_i) d_{i-j}^{-2}}{\sum_{i=1}^n d_{i-j}^{-2}}$$

where $z(x_j)$ is the value of the variable z at an unvisited point x , and d is a reciprocal exponential function.

The surface which results from the use of a weighted average technique is dependent upon the function type and parameters used, and on the size of the domain or window from which the sample data points are drawn.

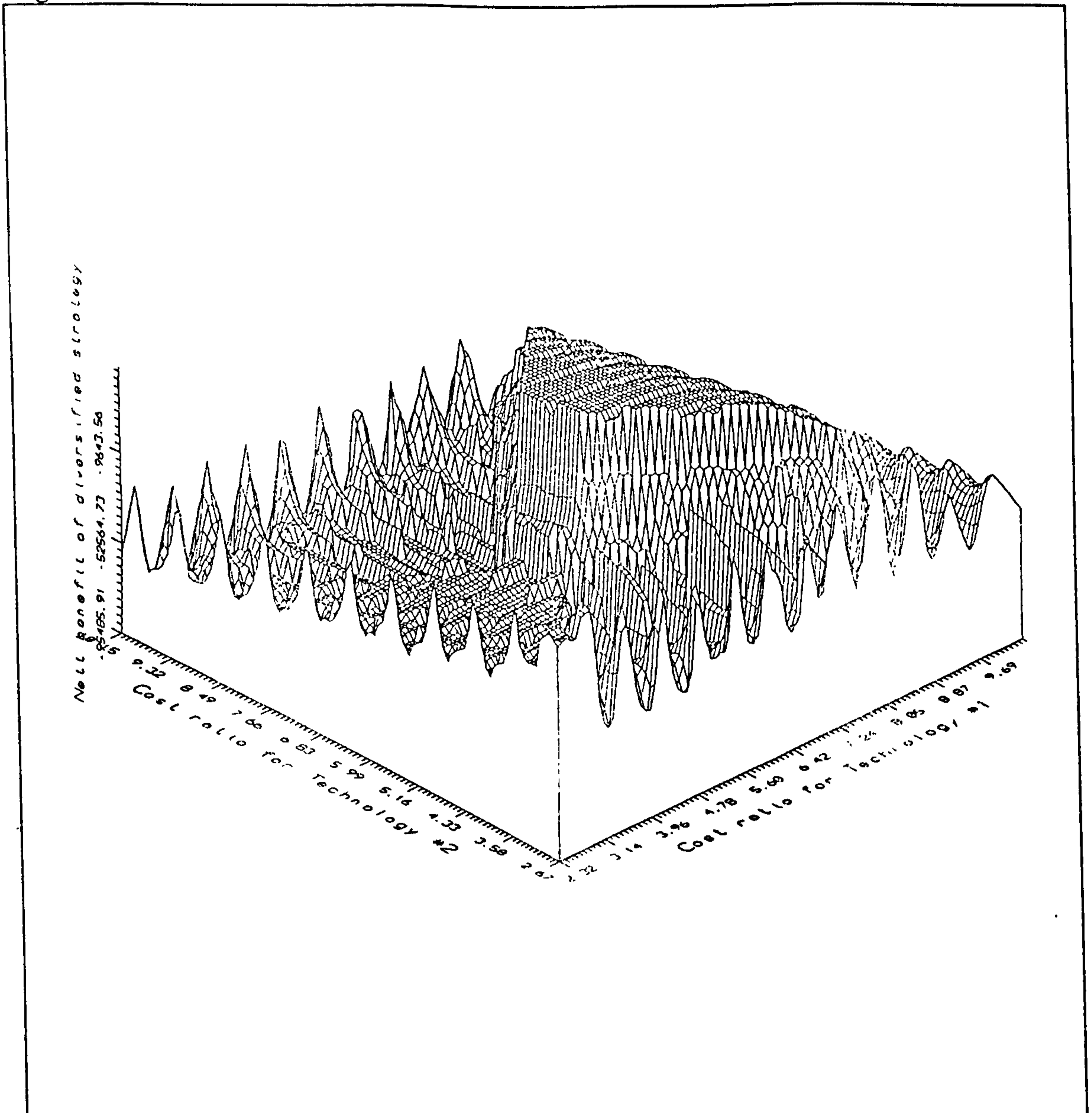
The values estimated by moving averages have been found to be unduly affected by clustering in the data points and also by the existence of planar trends (see Ripley, B. 'Spatial Statistics.' Wiley. New York. 1981). A point worth noting about all interpolation techniques is that because they are essentially smoothing operations, maxima and minima can only occur where actual data points are available. A corrective algorithm to provide an alternative set of points involves a computation of the slope of the interpolated surface at each data point which is used to project the form of the surface.

Figure A1-6



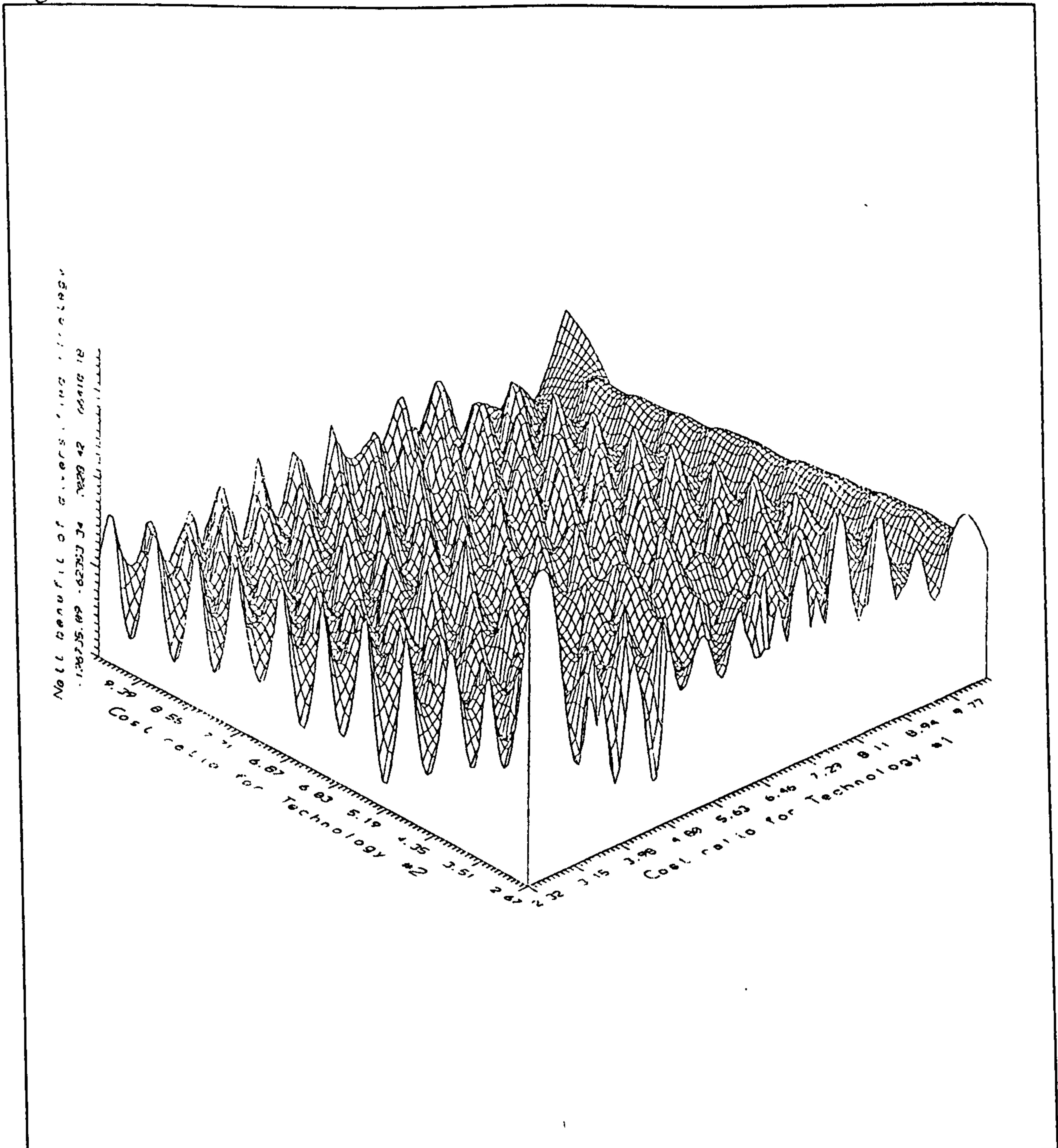
Kriging (Ref Figure A1-7), relies on a geostatistical technique to calculate the autocorrelation between data points and produce a minimum variance unbiased estimate of the missing value. The method rests on the proposition that the spatial variation of points on the surface is too irregular to be modelled by a smooth mathematical function but can be better described by a stochastically derived surface. Interpolation thereby proceeds by first exploring and then modelling the stochastic aspects of the regionalised variable. Resulting information is then used to estimate a series of weightings to be used during the interpolation process. The effectiveness of kriging is dependent upon the validity of certain important assumptions and the variables attributed to the parameters which describe structural, spatial and noise related characteristics. These values are set internally by the graphics program and were therefore not available for alteration.

Figure A1-7



Minimum curvature (ref Figure A1-8), honours the original data set by first setting all the grid nodes nearest to a data point to that value. The values of other grid nodes are then computed to provide a surface of minimum curvature through the set of nodes. If data are poorly distributed, the results for sub-regions using this method may be erratic. Additionally, any extrapolation of the data into regions with no data or use of this technique with noisy data should be carried out with caution.

Figure A1-8



The major difference between the three types of search method available concerns the scope of influence which is used to determine missing points. A normal search (Figure A1-9) will use the N nearest data points around the current grid node that are also within the specified search radius. The quadrant and octant search methods (Figs A1-10 and A1-11 respectively), are similar to the normal method but force the application of the search to each quadrant (90 degree) or octant (45 degree) sector in turn thereby ensuring that data points from all sides of the grid are used rather than from just one direction.

Figure A1-9

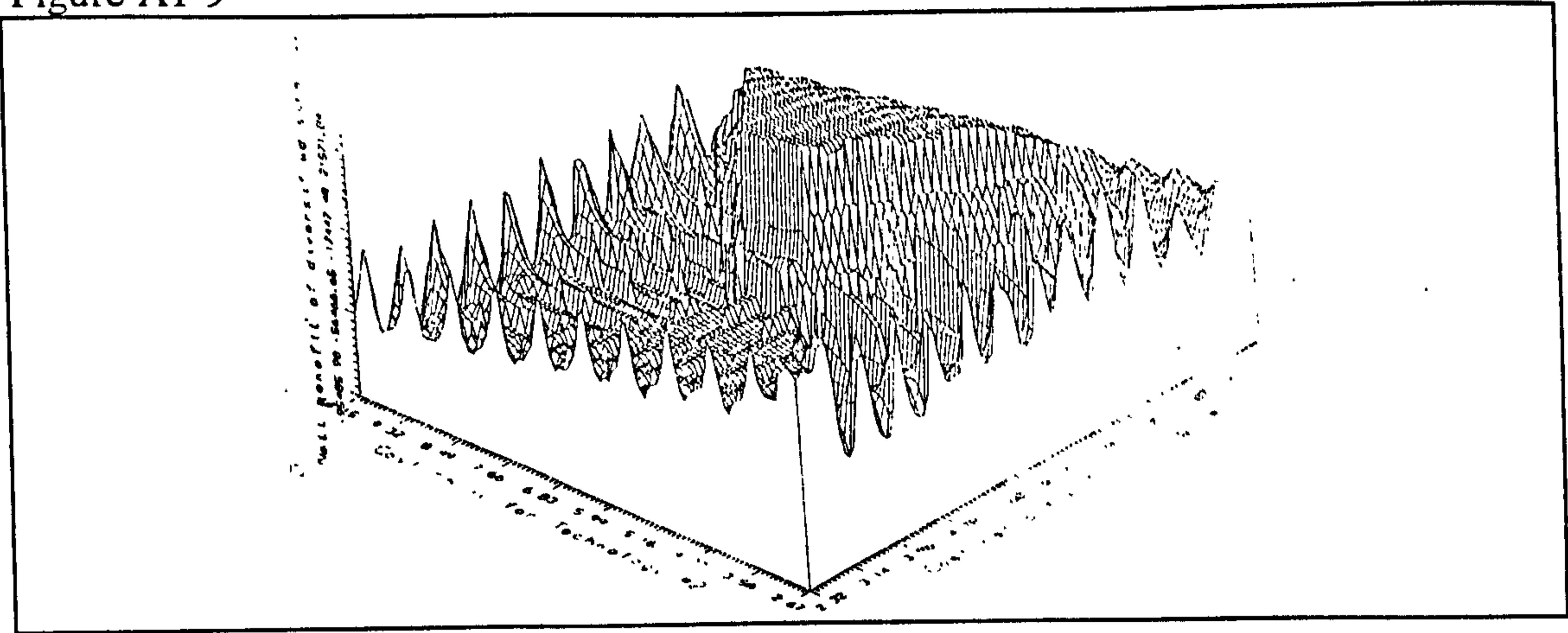


Figure A1-10

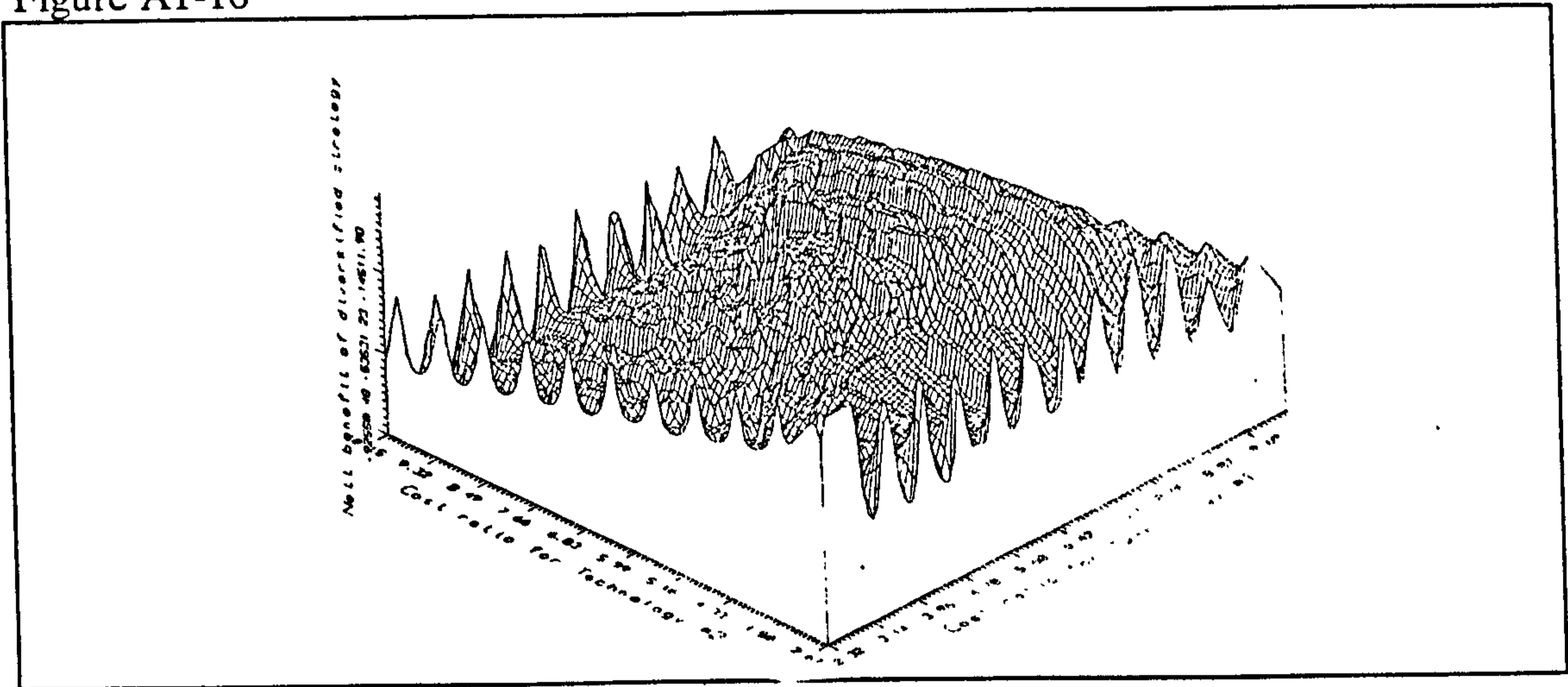
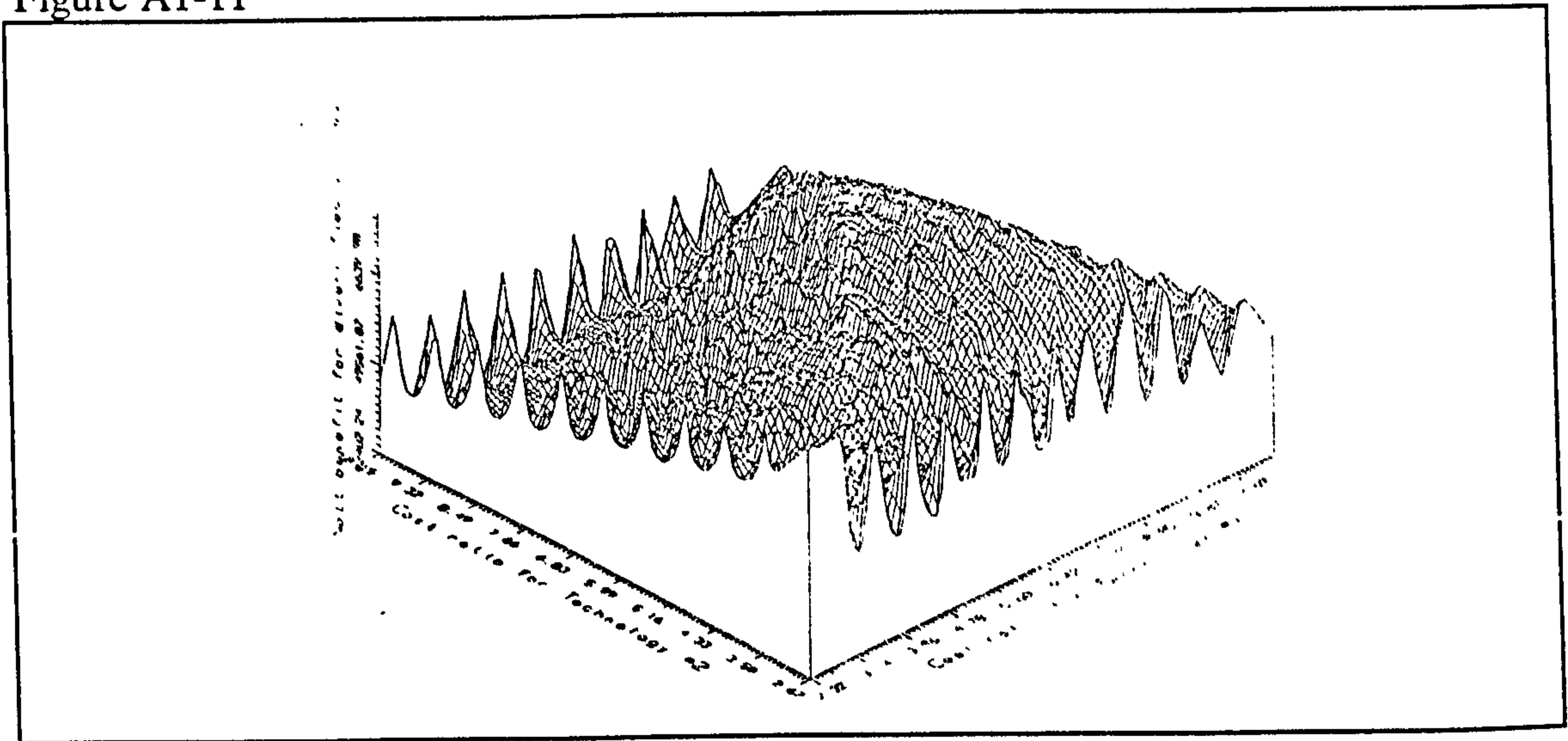


Figure A1-11



Assessing the validity of each of the above itemised search and gridding methods requires an appreciation of the type of data being generated as output from the computer model. As was described earlier, the aim of the model is to investigate the utility of certain investment strategies under conditions of dynamic cost functions. Accordingly, several key variable input parameters are generated stochastically and the model's own structure involves the use of multiple iterations. Any output will consequently be of a stochastic nature and will not lend itself to some types of description. Reference to figures A1-6 to A1-11 indicate that whilst the key features of the surface are present in each case, some methods serve to emphasise certain trends whilst others result in a damping effect. The main characteristic of the surfaces however is the dominance of peaks and troughs over several sub regions and, in the case of the figure generated by the minimum curvature gridding technique, over the whole surface.

Selection of one method for further use can be achieved by a partial interpretation of the results depicted so as to ascertain which key trends will need to be identified. Interpreting the surfaces with reference to the broad aims of the model suggests that attempts to relocate the organisation to a specific point on the surface expose it to potential relative losses when compared with the single technology option. Despite this, there is a broad identifiable trend which associates a general increase in utility with reductions in the value represented by the y axis. Reference to the figures representing alternative methods confirm that this result is common to all forms of output irrespective of the type of gridding and search method used.

A better way to depict the data set which the model generates would be by way of an envelope which represents the upper and lower bounds of the stochastic elements of the output. Failing this, a realistic representation of the broad trends which the surface suggests can be achieved by the kriging method with an octant search scope. This will ensure that local trends are maintained and provide a robust indication of the main characteristics of the data set. Additionally, kriging is generally accepted as the most ideal interpolator (see discussion in Burrough, P.A. 'Principles of Geographical Information Systems for Land Resources Assessment.' Clarendon Press. Oxford. 1991.), and this allows its use in the context of the model's output to be adapted to that of a trend indicator. The use of an octant searching scope will enhance the accuracy of the interpolated points, particularly in relation to the inter-ratio trends. Consequently, all subsequent surfaces presented hereafter were generated using this selected method.

One consequence of using the selected method is that the grid nodes around the periphery of each surface, whilst exhibiting a more accurate representation of the actual data points, will not have enough surrounding nodes with values to allow the octant search method to have as influential an effect as it does on points interior to the edge. A 'crown' effect is consequently generated as a result of this computational variability in interpolation, resulting in each surface being rimmed with areas of high data fluctuations.

The disparities between the surfaces which result from the use of different search and gridding methods are undoubtedly non trivial in both scope and magnitude. This highlights the discrepancies which could develop in data sets of this kind if care is not taken during both presentation and interpretation of model output. In particular the ramifications for model development are of interest and suggest that the form and pattern of model output need to be determined and understood at an early stage. In the instance reported above, the source of many of the identified problems surround the depiction of non-spatial data in a spatially bounded presentation. Advantages of this type of output include ease of interpretation and enhanced identification of broad trends. However, as has been seen, inherent in the transformation of raw data to presentation quality graphics, there is vast potential for misrepresentation and ambiguity.

Computer Code Listings

The following pages provide annotated computer code listings for the two 'C' programs developed during the course of the research. The first listing is of the DIVERS(X) program which operates as a single file model. The second listing is of the LTIME core file which accesses the following three listings to provide the modularity discussed in Chapter 4. (For the sake of clarity and brevity only one example configuration / strategy is depicted).

```
/*
```

DIVERS 'X'

'C' PROGRAM TO ANALYSE THE EFFECTS OF DIVERSITY ON THE RELATIVE PERFORMANCE OF INVESTMENT STRATEGIES

PAUL JEFFREY. INTA/MERC
CRANFIELD INSTITUTE OF TECHNOLOGY
1992

```
*/
```

```
#include <bios.h>  
#include <string.h>  
#include <stdio.h>  
#include <process.h>  
#include <graph.h>  
#include <stdlib.h>  
#include <conio.h>  
#include <pgchart.h>  
#include <math.h>  
#define FALSE 0  
#define TRUE 1  
#define LABEL 1  
#define BLUE 1  
#define RED 4  
#define YELLOW 14  
#define MAGENTA 5  
#define GREEN 2  
#define const 0.0000305185091
```

```
#define years 50
```

```
float _far categs[5000];
```

```
/* Preprocessor include directives for standard libraries etc */
```

```
/* Token replacement declarations */
```

```
/* Define number of years which simulation will run over */
```

```

float _far vals[5000];
char _far *labels[LABEL] = {"A over B"
};
float _far g2categs[4][50];
float _far g2vals[4][50];
char _far *g2labels[4] = {"CAP COST 1",
"CAP COST 2",
"OP COST 1",
"OP COST 2",
};
char _far *pg1labels[1] = {"Sequential Random Values",
};
char _far *pg2labels[1] = {"Selected p.d.f.",
};
chartenv env;

FILE *parafile;
FILE *datafile;
FILE *fcategs;
FILE *fvals;
FILE *costfile;

char change, resp;
float u1, u2, b, s, rnd, diff, s, FACCCOST, FBCCOST;

int kc=0, lc=0, ko=0, lo=0, m=0, n=0;
float kcp=0.0, lcp=0.0, lop=0.0, kop=0.0;

char dafile[15]="DFILE", pafile[15]="PFILE";
char cofile[15]="CFILE", str2[10], str3[20];

int view, YEAR, a, d, q, i, j, l, f, p, runs1, runs2, sims, indi;

```

/ Structure declarations for graphics sub routines */*

/ Declarations for files to be used for results storage */*

/ Variable declarations and initializations */*

/ Integer counting codes for cost accrual sub programs (array code versions) */*
/ Floating point markers for cost accrual sub programs (calculation versions) */*

/ File name kernels for result files to allow sequential recording of simulations */*

/ Integer counters for iterative loops etc */*


```

long seed;
/*
MT = MACRO TURBULENCE
X3 = CUBED ELEMENT OF COST FUNCTION
X2 = SQUARED ELEMENT OF COST FUNCTION
X = LINEAR ELEMENT OF COST FUNCTION
CON = CONSTANT ELEMENT OF COST FUNCTION
TF = TURBULENCE FACTOR
FF = FREQUENCY FACTOR
FT = FREQUENCY OF TURBULENCE FACTOR
*/

```

```

/* Suffix code information for cost generation equation variables */
/* (See accompanying text for explanation of the function of each variable type) */

```

```

/* Cost generation equation variable and variable bounds declarations */

```

```

double CC1MT, CC1XX3, CC1XX2, CC1XX, CC1CON, CC1TF, CC1FF, CC1FT;
float CC2MT, CC2X3, CC2X2, CC2X, CC2CON, CC2TF, CC2FF, CC2FT;
float OC1MT, OC1X3, OC1X2, OC1X, OC1CON, OC1TF, OC1FF, OC1FT;
float OC2MT, OC2X3, OC2X2, OC2X, OC2CON, OC2TF, OC2FF, OC2FT;
float CC1MTMAX = 0.5, CC1XX3MAX = 0.5, CC1XX2MAX = 0.5, CC1XXMAX = 0.5, CC1CONMAX = 15000.0;
float CC1TFMAX = 0.5, CC1FFMAX = 0.5, CC1FTMAX = 0.5;
float CC2MTMAX = 0.5, CC2X3MAX = 0.5, CC2X2MAX = 0.5, CC2XMAX = 0.5, CC2CONMAX = 55000.0;
float CC2TFMAX = 0.5, CC2FFMAX = 0.5, CC2FTMAX = 0.5;
float CC1MTMIN = 0.5, CC1XX3MIN = 0.5, CC1XX2MIN = 0.5, CC1XXMIN = 0.5, CC1CONMIN = 15000.0;
float CC1TFMIN = 0.5, CC1FFMIN = 0.5, CC1FTMIN = 0.5;
float CC2MTMIN = 0.5, CC2X3MIN = 0.5, CC2X2MIN = 0.5, CC2XMIN = 0.5, CC2CONMIN = 55000.0;
float CC2TFMIN = 0.5, CC2FFMIN = 0.5, CC2FTMIN = 0.5;
float OC1MTMAX = 0.2, OC1X3MAX = 2.0, OC1X2MAX = 9.2, OC1XMAX = 4.0, OC1CONMAX = 7000.0;
float OC1TFMAX = 600, OC1FF = 0.2, OC1FTMAX = 0.6;
float OC2MTMAX = 0.6, OC2X3MAX = 4.8, OC2X2MAX = 8.0, OC2XMAX = 12.0, OC2CONMAX = 6000.0;
float OC2TFMAX = 800, OC2FF = 0.2, OC2FTMAX = 0.75;
float OC1MTMIN = 0.1, OC1X3MIN = 1.0, OC1X2MIN = 4.0, OC1XMIN = 2.2, OC1CONMIN = 6000.0;
float OC1TFMIN = 300, OC1FTMIN = 0.3;
float OC2MTMIN = 0.4, OC2X3MIN = 3.4, OC2X2MIN = 4.0, OC2XMIN = 3.5, OC2CONMIN = 5000.0;

```

```

float OC2TFMIN = 400, OC2FTMIN = 0.62;
float CCTURBFAC = 0.0, SWITCHFACT = 0.0; OCTURBFAC = 0.0;
float TICCOST, T2CCOST, T1OCOST, T2OCOST;
float OCOSTSA, OCOSTSB, CCOSTSA, CCOSTSB, AOVERB;
float _far RATIOARRAY[100][2];
float _far RATIO2ARRAY[100][2];
float _far COSTARRAY[years][4];
float _far MIXARRAY[5000];
float _far RESULTARRAY[5000];
float _far CCTURBARRAY[5000];
float _far OCTURBARRAY[5000];
float _far RANDARRAY[5000];
float _far PROBARRAY[5000][2];
float XVALREF[years][4];

void init_xvalref(void);
void calc_ccosts(void);
void calc_ocosts(void);
void init_graphics(void);
void print_states(void);
void graph1(void);
void graph2(void);
void calc_variables(void);
void prob_graph1(void);
void prob_graph2(void);
float rand_gen(float,float);
short _far _setwindow(short flg_invert, double wx1, double wy1, double wx2, double wy2);

```

/ Temporary and result array declarations */*

/ Sub function declarations */*

/ Main function - Prompts for number of simulations and allows default variable range settings to be altered. Calls functions to set variables and calculates cost profiles for each simulation. */*

```

main()
{
    printf("\n\nPlease input the file number for results ");
    scanf("%s",&str2);
    strcat(dafile,str2);
    strcat(dafile,".XLD");
    if((datafile=fopen(dafile,"w")) == NULL)
    {
        perror("fileopen failed");
        exit(1);
    }
    strcat(pafile,str2);
    strcat(pafile,".XLD");
    if((parafile=fopen(pafile,"w")) == NULL)
    {
        perror("fileopen failed");
        exit(1);
    }
    strcat(cofile,str2);
    strcat(cofile,".XLD");
    if((costfile=fopen(cofile,"w")) == NULL)
    {
        perror("fileopen failed");
        exit(1);
    }
    printf("\nSet switchfact = ");
    scanf("%f",&SWITCHFACT);
    for(runs1=0;runs1<10;runs1++)
    {
        /* Prompt user for file number for creation of results file */
        /* Concatenate filename and open */
        /* Create and open parameter record file */
        /* Create and open cost history rrecord file */
        /* Prompt user to provide factor by which diversified firm is penalised
           for switching between technologies */
        /* Outer simulation loop counter */

```

```

for(runs2=0;runs2<10;runs2++)
{
    /* Inner simulation loop counter */
    /* Print cost generation equation variables to parameter file */
    fprintf(parafile,"CC1MTMAX \t %.2fnCC1XX3MAX \t %.2fnCC1XX2MAX \t %.2fnCC1XXMAX \t %.2fnCC1CONMAX \t %.2fn\
    CC1TFMAX \t %.2fnCC1FFMAX \t %.2fnCC1FTMAX \t %.2fn\
    CC2MTMAX \t %.2fnCC2X3MAX \t %.2fnCC2X2MAX \t %.2fnCC2XMAX \t %.2fnCC2CONMAX \t %.2fn\
    CC2TFMAX \t %.2fnCC2FFMAX \t %.2fnCC2FTMAX \t %.2fn\
    CC1MTMIN \t %.2fnCC1XX3MIN \t %.2fnCC1XX2MIN \t %.2fnCC1XXMIN \t %.2fnCC1CONMIN \t %.2fn\
    CC1TFMIN \t %.2fnCC1FFMIN \t %.2fnCC1FTMIN \t %.2fn\
    CC2MTMIN \t %.2fnCC2X3MIN \t %.2fnCC2X2MIN \t %.2fnCC2XMIN \t %.2fnCC2CONMIN \t %.2fn\
    CC2TFMIN \t %.2fnCC2FFMIN \t %.2fnCC2FTMIN \t %.2fn\
    OC1MTMAX \t %.2fnOC1X3MAX \t %.2fnOC1X2MAX \t %.2fnOC1XMAX \t %.2fnOC1CONMAX \t %.2fn\
    OC1TFMAX \t %.2fnOC1FF \t %.2fnOC1FTMAX \t %.2fn\
    OC2MTMAX \t %.2fnOC2X3MAX \t %.2fnOC2X2MAX \t %.2fnOC2XMAX \t %.2fnOC2CONMAX \t %.2fn\
    OC2TFMAX \t %.2fnOC2FF \t %.2fnOC2FTMAX \t %.2fn\
    OC1MTMIN \t %.2fnOC1X3MIN \t %.2fnOC1X2MIN \t %.2fnOC1XMIN \t %.2fnOC1CONMIN \t %.2fn\
    OC1TFMIN \t %.2fnOC1FTMIN \t %.2fn\
    OC2MTMIN \t %.2fnOC2X3MIN \t %.2fnOC2X2MIN \t %.2fnOC2XMIN \t %.2fnOC2CONMIN \t %.2fn\
    OC2TFMIN \t %.2fnOC2FFMIN \t %.2fnOC2X2MAX, CC1XX3MAX, CC1XX2MAX, CC1XXMAX, CC1CONMAX, \
    CC1TFMAX, CC1FFMAX, CC1FTMAX, CC2MTMAX, CC2X3MAX, CC2X2MAX, CC2XMAX, CC2CONMAX, \
    CC2TFMAX, CC2FFMAX, CC2FTMAX, CC1XX3MIN, CC1XX2MIN, CC1XXMIN, CC1CONMIN, \
    CC1TFMIN, CC1FFMIN, CC1FTMIN, CC2MTMIN, CC2X3MIN, CC2X2MIN, CC2XMIN, CC2CONMIN, \
    CC2TFMIN, CC2FFMIN, CC2FTMIN, OC1MTMAX, OC1X3MAX, OC1X2MAX, OC1XMAX, OC1CONMAX, \
    OC1TFMAX, OC1FF, OC1FTMAX, OC2MTMAX, OC2X3MAX, OC2X2MAX, OC2XMAX, OC2CONMAX, \
    OC2TFMAX, OC2FF, OC2FTMAX, OC1MTMIN, OC1X3MIN, OC1X2MIN, OC1XMIN, OC1CONMIN, \
    OC1TFMIN, OC1FTMIN, OC2MTMIN, OC2X3MIN, OC2X2MIN, OC2XMIN, OC2CONMIN, \
    OC2TFMIN, OC2FTMIN);
    sims = 10;
    for (a=0;a<sims;a++)
    {
        RESULTARRAY[a] = 0;
        CCTURBARRAY[a] = 0;
        OCTURBARRAY[a] = 0;
    }
}
/* Initialize arrays */

```

```

    }
    for (a=0;a<sims;a++)
    {
        for(f=0;f<2;f++)
        {
            RATIO2ARRAY[a][f] = 0;
        }
    }
    for (q=0;q<sims;q++)
    {
        init_xvalref0;
        OCOSTSA = OC1CONMAX;
        MIXARRAY[0] = 1.0;
        for(p=0;p<years;p++)
        {
            calc_variables0;
            calc_ccosts0;
            calc_ocosts0;

            CCTURBARRAY[q] += CCTURBFAC;
            RESULTARRAY[q] += ((CCOSTSB+OCOSTSB)-(CCOSTSA+OCOSTSA));
            RATIO2ARRAY[q][0] += T1OCOST;
            RATIO2ARRAY[q][1] += T2OCOST;
        }

        RATIOARRAY[q][0]=(COSTARRAY[0][0]/(RATIO2ARRAY[q][0]/years));
        RATIOARRAY[q][1]=(COSTARRAY[0][1]/(RATIO2ARRAY[q][1]/years));
        OCTURBARRAY[q] = OCTURBARRAY[q]/years;
    }
    graph10;
    graph20;
}
/* Call graphing functions */

```

/ Main simulation loop */*

/ Call function to determine number of time steps to utilise for use in cost generation equation */*

/ Provide reference value for equation */*

/ Set array which determines whether a technology switch has occurred to 0 for year 1 */*

/ Start of years loop */*

/ Call function to calculate values for cost equation variables */*

/ Call function to evaluate capital costs for each technology */*

/ Call function to evaluate operating costs for each technology */*

/ Calculate turbulence factor values (only utilised in earlier versions of program)
and ratio values */*

/ Evaluate technology cost ratios */*

/ Call graphing functions */*

```

getch();
for(i=0;i<sims;i++)
{
    printf(datafile, "%.2f\t%.2f\t%.2f\n", RATIOARRAY[i][0], RATIOARRAY[i][1], RESULTARRAY[i]);
}
for(a=0;a<years;a++)
{
    printf(costfile, "%.2f\t%.2f\t%.2f\n", COSTARRAY[a][0], COSTARRAY[a][1], COSTARRAY[a][2], COSTARRAY[a][3]);
}
    CC1CONMAX += 4000.0;
    CC1CONMIN += 4000.0;
}
    CC1CONMAX = 15000.0;
    CC1CONMIN = 15000.0;
    CC2CONMAX -= 4000.0;
    CC2CONMIN -= 4000.0;
}
fclose(datafile);
fclose(parafile);
fclose(costfile);
graph10;
graph20;
prob_graph10;
prob_graph20;
}

/* Print results to data files */

/* Increment technology #1 cost equation constants to generate variations in cost ratios */

/* Reset technology #1 cost equation constant and increment
    technology #2 cost equation constant */

/* Close data files */

/* Call graphing functions */

/* End of main function */

/* Function to initialize the time step for cost generation equations (determined by the frequency
    factor variable initialized in the preprocessor commands) */

void init_xvalref(void)
{
    for(j=0;j<years;j++)

```

```

{
XVALREF[j][0] = j*CC1FF;
XVALREF[j][1] = j*CC2FF;
XVALREF[j][2] = j*OC1FF;
XVALREF[j][3] = j*OC1FF;
}
}

```

/ Function to attribute a value to each component of the cost generation equation.
Accesses random number generator and bounds declared in variable declaration section (above) */*

```

void calc_variables(void)
{
    seed = (q*years)+p;
    srand(seed);
    indi = 0;
    CC1MT = rand_gen(CC1MTMAX,CC1MTMIN);
    CC2MT = rand_gen(CC2MTMAX,CC2MTMIN);
    CC1XX3 = rand_gen(CC1XX3MAX,CC1XX3MIN);
    CC1XX2 = rand_gen(CC1XX2MAX,CC1XX2MIN);
    CC1XX = rand_gen(CC1XXMAX,CC1XXMIN);
    CC1CON = rand_gen(CC1CONMAX,CC1CONMIN);
    CC1TF = rand_gen(CC1TFMAX,CC1TFMIN);
    CC1FF = rand_gen(CC1FFMAX,CC1FFMIN);
    CC1FT = rand_gen(CC1FTMAX,CC1FTMIN);
    CC2X3 = rand_gen(CC2X3MAX,CC2X3MIN);
    CC2X2 = rand_gen(CC2X2MAX,CC2X2MIN);
    CC2X = rand_gen(CC2XMAX,CC2XMIN);
    CC2CON = rand_gen(CC2CONMAX,CC2CONMIN);
    CC2TF = rand_gen(CC2TFMAX,CC2TFMIN);
    CC2FF = rand_gen(CC2FFMAX,CC2FFMIN);
    CC2FT = rand_gen(CC2FTMAX,CC2FTMIN);
    OC1MT = rand_gen(OC1MTMAX,OC1MTMIN);

```

/ Use years value and simulation run value to determine seed for random number generator */
/* Call random number generator function (internally defined 'c' math function) */
/* Set counter for random number algorithm to 0 */*

/ Sequentially call random number algorithm for each cost equation variable */
/* Pass the upper and lower bound values as arguments to function */*

```

OC2MT = rand_gen(OC2MTMAX,OC2MTMIN);
OC1X3 = rand_gen(OC1X3MAX,OC1X3MIN);
OC1X2 = rand_gen(OC1X2MAX,OC1X2MIN);
OC1X  = rand_gen(OC1XMAX,OC1XMIN);
OC1CON = rand_gen(OC1CONMAX,OC1CONMIN);
OC1TF  = rand_gen(OC1TFMAX,OC1TFMIN);
OC1FT  = rand_gen(OC1FTMAX,OC1FTMIN);
OC2X3  = rand_gen(OC2X3MAX,OC2X3MIN);
OC2X2  = rand_gen(OC2X2MAX,OC2X2MIN);
OC2X   = rand_gen(OC2XMAX,OC2XMIN);
OC2CON = rand_gen(OC2CONMAX,OC2CONMIN);
OC2TF  = rand_gen(OC2TFMAX,OC2TFMIN);
OC2FT  = rand_gen(OC2FTMAX,OC2FTMIN);
}

```

/ Random number generator function and conversion routine to scale result into variable range.
Takes maximum and minimum bounds as arguments */*

```

float rand_gen(float rangmax,float rangmin)
{
if (indi == 1)
{
    rnd = b*u2;
}
else
{
    ll: u1 = 2*(const*rand0)-1;
    u2 = 2*(const*rand0)-1;
    s = (u1*u1)+(u2*u2);
    if (s>=1 || s<=0)
    {
        goto ll;
    }
    b = pow((-2.0*(log(s)/s)),0.5);
}
}

```



```

    rmd = b*u1;
  }
  if (indi == 0)
  {
    indi=1;
  }
  else
  {
    indi=0;
  }
  RANDARRAY[q*years+p] = rmd;
  rmd = (rmd+4)*100;
  rmd = rmd/800;
  diff = (rangmax-rangmin)*100;
  rmd = (rmd*diff)/100+rangmin;
  return rmd;
}

```

/ Function to calculate the capital cost profiles for each technology.*/*

```

void calc_ccosts(void)
{
  /* Code applying to technology #1 */

  if(rand0<32767*CC1MT || COSTARRAY[p-1][0] < COSTARRAY[0][0] * 0.05)  /* Selects macro-turbulence status and tests for 'bottoming out' of
  {                                                                                                                function */
    kc=0;                                                                                                           /* Set counters */
    kcp=0.0;                                                                                                       /* Select frequency of turbulence status for negative case of macro turbulence status*/
    if(rand0<32767*CC1FT)
    {
      /* Calculate capital cost value for positive case*/

      TICCOST = sin(((CC1XX3*pow(XVALREF[kc][0],3.0))+(CC1XX2*pow(XVALREF[kc][0],2.0))
      +(CC1XX*XVALREF[kc][0]+CC1CON))-(360.0*XVALREF[kc][0]+1.0))*CC1TF+(CC1XX2*pow(kcp,2.0)+CC1XX*kcp+CC1CON);
    }
  }
}

```

```

}
else
{
/* Calculate capital cost value for negative case */
T1CCOST = (CC1XX2*pow(XVALREF[p][0],2.0)+CC1XX*XVALREF[p][0]+CC1CON);
}
}
else
{
if(rand0<32767*CC1FT)
{
/* Select frequency of turbulence status for positive case of macro turbulence status */
/* Calculate capital cost value for positive case */
T1CCOST = sin((( -CC1XX3*pow(XVALREF[kc][0],3.0))+(-CC1XX2*pow(XVALREF[kc][0],2.0))
+(-CC1XX*XVALREF[kc][0]+CC1CON))-(360.0*XVALREF[kc][0]+1.0))*CC1TF+(-CC1XX2*pow(kcp,2.0)+-CC1XX*kcp+CC1CON);
}
}
else
{
/* Calculate capital cost value for negative case */
T1CCOST = (-CC1XX2*pow(kcp,2.0)+-CC1XX*kcp+CC1CON);
}
}
COSTARRAY[p][0] = T1CCOST;
kc+=1;
kcp += 1.0;
/* Assign calculated cost to relevant array */
/* Increment Counters */
/* Code applying to technology #2 (identical to that for technology #1) */
if(rand0<32767*CC2MT || COSTARRAY[p-1][1] < COSTARRAY[0][1] * 0.05)
{
lc=0;
lcp=0.0;
if(rand0<32767*CC2FT)
{
T2CCOST = sin(((CC2X3*pow(XVALREF[lc][1],3.0))+(-CC2X2*pow(XVALREF[lc][1],2.0))
+(-CC2X*XVALREF[lc][1]+CC2CON))-(360.0*XVALREF[lc][1]+1.0))*CC2TF+(CC2X2*pow(lcp,2.0)+CC2X*lcp+CC2CON);
}
}
}
}

```

```

}
else
{
T2CCOST = (CC2X2*pow(XVALREF[p][1],2.0)+CC2X*XVALREF[p][1]+CC2CON);
}
}
else
{
if(rand0<32767*CC2FT)
{
T2CCOST = sin((( -CC2X3*pow(XVALREF[ic][1],3.0))+(-CC2X2*pow(XVALREF[ic][1],2.0))
+(-CC2X*XVALREF[ic][1]+CC2CON))-(360*XVALREF[ic][1]+1))*CC2TF+(-CC2X2*pow(lcp,2))+CC2X*lcp+CC2CON);
}
}
else
{
T2CCOST = (-CC2X2*pow(lcp,2.0))+CC2X*lcp+CC2CON);
}
}
COSTARRAY[p][1] = T2CCOST;
lcp+=1;
lcp+=1.0;
if(p == 0)
{
CCOSTSA = T1CCOST+T2CCOST;    /* Assign capital costs for each firm if year 1 */
CCOSTSB = T1CCOST;
}
else
{
CCOSTSA = 0;
CCOSTSB = 0;
}
}
}
}

CCTURBFAC = CC1FT+CC2FT+CC1MT+CC2MT+CC1FF+CC2FF+(CC1TF/T1CCOST)+(CC2TF/T2CCOST);
CCTURBFAC = CCTURBFAC/years;

```

/ Assign turbulence factors (used in early versions of model) */*

```

}

/* Function to calculate the operating cost profiles for each cost element.
   Utilises identical code to capital cost function */

void calc_ocosts(void)
{
    if(rand()<32767*OC1MT || COSTARRAY[p-1][2] < COSTARRAY[0][2] * 0.05)
    {
        ko=0;
        kop=0.0;
        if(rand()<32767*OC1FT)
        {
            T1OCOST = sin(((OC1X3*pow(XVALREF[ko][2],3.0))+(OC1X2*pow(XVALREF[ko][2],2.0))
            +(OC1X*XVALREF[ko][2]+OC1CON))-(360.0*XVALREF[ko][2]+1.0))*OC1TF+(OC1X2*pow(kop,2.0)+OC1X*kop+OC1CON);
        }
        else
        {
            T1OCOST = (OC1X2*pow(XVALREF[p][2],2.0)+OC1X*XVALREF[p][2]+OC1CON);
        }
    }
    else
    {
        if(rand()<32767*OC1FT)
        {
            T1OCOST = sin(((OC1X3*pow(XVALREF[ko][2],3.0))+(OC1X2*pow(XVALREF[ko][2],2.0))
            +(-OC1X*XVALREF[ko][2]+OC1CON))-(360.0*XVALREF[ko][2]+1.0))*OC1TF+(-OC1X2*pow(kop,2.0)+OC1X*kop+OC1CON);
        }
        else
        {
            T1OCOST = (-OC1X2*pow(kop,2.0)+OC1X*kop+OC1CON);
        }
    }
    COSTARRAY[p][2] = T1OCOST;
}

```

```

ko+=1;
kop+=1.0;
if(rand0<32767*OC2MT || COSTARRAY[p-1][3] < COSTARRAY[0][3] * 0.05)
{
lo=0;
lop=0.0;
if(rand0<32767*OC2FT)
{
T2OCOST = sin(((OC2X3*pow(XVALREF[lo][3],3.0))+(OC2X2*pow(XVALREF[lo][3],2.0))
+(OC2X*XVALREF[lo][3]+OC2CON))-(360.0*XVALREF[lo][3]+1.0))*OC2TF+(OC2X2*pow(lop,2.0)+OC2X*lop+OC2CON);
}
else
{
T2OCOST = (OC2X2*pow(XVALREF[p][3],2.0)+OC2X*XVALREF[p][3]+OC2CON);
}
}
else
{
if(rand0<32767*OC2FT)
{
T2OCOST = sin(((OC2X3*pow(XVALREF[lo][3],3.0))+(OC2X2*pow(XVALREF[lo][3],2.0))
+(OC2X*XVALREF[lo][3]+OC2CON))-(360.0*XVALREF[lo][3]+1.0))*OC2TF+(-OC2X2*pow(lop,2.0)+OC2X*lop+OC2CON);
}
else
{
T2OCOST = (-OC2X2*pow(lop,2.0)+OC2X*lop+OC2CON);
}
}
COSTARRAY[p][3] = T2OCOST;
lo+=1;
lop+=1.0;

```

/ Assess which technology the diversified firm should access (minimum cost criteria). Update arrays and apply switchfactor to determine additional cost penalty for switch */*

```

if(COSTARRAY[p][2] < COSTARRAY[p][3] && MIXARRAY[(q*years)+(p-2)] == 2.0)
{
OCOSTSA = T1OCOST;
MIXARRAY[(q*years)+p] = 1.0;
}
else if(COSTARRAY[p][3] < COSTARRAY[p][2] && MIXARRAY[(q*years)+(p-2)] == 1.0)
{
OCOSTSA = T2OCOST;
MIXARRAY[(q*years)+p] = 2.0;
}
else if (p == 0)
{
MIXARRAY[(q*years)+p] = 1.0;
}
else
{
MIXARRAY[(q*years)+p] = MIXARRAY[(q*years)+p-1];
}
if(MIXARRAY[(q*years)+p] != MIXARRAY[(q*years)+p-2])
{
OCOSTSA = OCOSTSA*(1+SWITCHFACT);
OCTURBARRAY[q] += 1;
}
OCOSTSB = T1OCOST;
}

```

/ Graph function to plot a scatterchart of environmental turbulence against the cost differential of the two adopted strategies. */*

```

void graph1(void)
{
_setvideomode(_VRES16COLOR);
_setwindow(0,0,640,480);
}

```

```

    _rectangle(_GBORDER,10,10,630,460);
    _setviewport(0,0,640,480);
    _clearscreen(_GVIEWPORT);
    _pg_initchart();
    _pg_defaultchart(&env,_PG_SCATTERCHART,_PG_POINTONLY);
    strcpy(env.xaxis.axisitle.title,"RATIO OF T1 OP COST TO T2 OP COST");
    strcpy(env.yaxis.axisitle.title,"TOTAL COST OVER years YEARS");
    _pg_chartscatter(&env,OCTURBARRAY,RESULTARRAY,sims);
    getch();
    _setvideomode(_DEFAULTMODE);
}

```

/ Graphing function to depict the final simulation's cost profiles as an indication of the generalised trend */*

```

void graph2(void)
{
    _setvideomode(_DEFAULTMODE);
    printf("\n\nFinal simulation cost functions shown...\n");
    getch();
    _setvideomode(_VRES16COLOR);
    _setwindow(0,0,0,640,480);
    _rectangle(_GBORDER,10,10,630,460);
    _setviewport(0,0,640,480);
    _clearscreen(_GVIEWPORT);
    for(i=0;i<years;i++)
    {
        for(j=0;j<4;j++)
        {
            g2categs[j][i]=i;
        }
    }
    for(i=0;i<years;i++)
    {

```

```

for(j=0;j<4;j++)
{
    g2vals[j][i]=COSTARRAY[i][j];
}
    }
    _pg_initchart();
    _pg_defaultchart(&env,_PG_SCATTERCHART,_PG_POINTANDLINE);
    strcpy(env.xaxis.axisitle.title,"YEAR");
    strcpy(env.yaxis.axisitle.title,"COST");
    _pg_chartscatterms(&env,(float _far *)g2cats,(float _far *)g2vals,4,years,g2labels);
    getch();
    _setvideomode(_DEFAULTMODE);
}

```

/ Graph functions to plot the probability distribution as generated by the random number function. */*

```

void prob_graph1(void)
{
    _setvideomode(_VRES16COLOR);
    _setwindow(0,0,0,640,480);
    _rectangle(_GBORDER,10,10,630,460);
    _setviewport(0,0,640,480);
    _clearscreen(_GVIEWPORT);
    for(i=0;i<sims*years;i++)
    {
        cats[i]=i;
    }
    _pg_initchart();
    _pg_defaultchart(&env,_PG_SCATTERCHART,_PG_POINTONLY);
    strcpy(env.xaxis.axisitle.title,"VALUES");
    strcpy(env.yaxis.axisitle.title,"PROBABILITY");
    _pg_chartscatterms(&env,cats,RANDARRAY,1,sims*years,sims*years,pg1labels);
    getch();
}

```



```

_setvideomode(_DEFAULTMODE);
}

void prob_graph2 (void)
{
_setvideomode(_VRES16COLOR);
_setwindow(0,0,0,640,480);
_rectangle(_GBORDER,10,10,630,460);
_setviewport(0,0,640,480);
_clearscreen(_GVIEWPORT);
for (i=0;i<sims*years;i++)
{
PROBARRAY[i][1] = 0;
}
s = -4;
for(l=0;l<100;l++)
{
for(j=0;j<sims*years;j++)
{
if(RANDARRAY[j] > s && RANDARRAY[j] <= s+0.08)
{
PROBARRAY[i][1] += 1;
}
}
PROBARRAY[i][0] = s;
s += 0.08;
}
for(i=0;i<100;i++)
{
categs[i]=PROBARRAY[i][0];
}
for(i=0;i<100;i++)
{
vals[i]=PROBARRAY[i][1];
}
}
}

```

```
    }
    _pg_initchart();
    _pg_defaultchart(&env, _PG_SCATTERCHART, _PG_POINTANDLINE);
    strcpy(env.xaxis.axistitle.title, "VALUES");
    strcpy(env.yaxis.axistitle.title, "PROBABILITY");
    _pg_chartscatterms(&env, (float _far *)vals, 1, 100, 100, pg2labels);
    getch();
    _setvideomode(_DEFAULTMODE);
}
```

/*

LTIME 'C'

**Program to analyse lead time and technology switching options for a two technology system.
Utilises an if statement to generate the operating cost hike**

Paul Jeffrey

INTA/IERC Cranfield Institute of Technology

1992

*/

```
#include <bios.h>
#include <string.h>
#include <stdio.h>
#include <process.h>
#include <graph.h>
#include <stdlib.h>
#include <conio.h>
#include <pgchart.h>
#include <math.h>
#define FALSE 0
#define TRUE 1
#define LABEL 1
#define BLUE 1
#define RED 4
#define YELLOW 14
#define MAGENTA 5
#define GREEN 2
#define years 50
#define runs 20
#define inner 10
#define outer 10
```

/ Preprocessor include statement for default libraries */*

/ Preprocessor define statements for constant expressions */*

```

extern int i, j, aa, bb, cc;
extern int loop1, loop2;
int l, m, p, swap;
extern int k;
float _far g1categs[5][years];
float _far g1vals[5][years];
char _far *g1labels[5] = {"CAP COST 1",
                        "CAP COST 2",
                        "OP COST 1",
                        "OP COST 2",
                        "OP INDEX",
                        };
float _far g2categs[4][years];
float _far g2vals[4][years];
char _far *g2labels[4] = {"OP INDEX",
                        "CAPAC INDEX",
                        "SYSRATS",
                        ""},
                        };

void strat_build(void);
void base_build(void);
void initialize(void);
void strat_op(void);
void coststm5(void);
void base_op(void);
void calc_basecosts(void);
void calc_stratcosts(void);
void calc_discosts(void);
void write_results1(void);
void write_results2(void);
void graph1(void);
void fileopen(void);
void fileclose(void);
extern double _far T1ARRAY[years][4];
extern double _far T2ARRAY[years][4];
float _far RATARRAY[inner*outer*runs][2];

```

/ Declaration of integer counters for iteration loops */*

/ Graphics function title labels */*

/ Sub-function declarations */*

```

double _far SYSARRAY[years][10];
double _far BASE_COSTS[years][8];
double _far STRAT_COSTS[years][8];
extern float _far COSTARRAY[years][8];
double COSTCODE[8];
extern float _far DEMAND_ARRAY[years];
double n, codenum;
float code, tempratio, tempcost, f, bavail, savail;
float bcapacity, scapacity, rate = 0.06;
float olearnfact=0.0, clearnfact=0.0, pen, costsop, costshold;
chartenv env;
FILE *sopsetdat;
FILE *bopsetdat;
FILE *sunitdat;
FILE *bunitdat;
FILE *costdem;
FILE *bfirmcost;
FILE *sfirmcost;
FILE *oddatt;
FILE *scaleinf;
FILE *deslifeinf;
FILE *oprats;
FILE *ratiodat;
FILE *simres;
float OPRATS[32];
float SCALEFUNC[16];
float DESLIFEFUNC[16];
short _far _setwindow(short flg_invert, double wx1, double wy1, double wx2, double wy2);
char file[10] = "LTFILE", str2[10], str3[20];
int lead1 = 3, lead2 = 4;
extern float BUNITCOUNT[2][2];
extern float SUNITCOUNT[2][2];
extern float BOPSETARRAY[40][12];
extern float SOPSETARRAY[40][12];
extern float BUNITSTATUS[40][years + 1];
extern float SUNITSTATUS[40][years + 1];

```

/ Array Declarations */*

/ Float counter declarations */*

/ Input and result file declarations */*

/ Externally accessed array declarations */*

```

extern float scapacity,bcapacity,mintec1,mintec2;
int typecode, temp, res, ii, mint1, mint2;

/* Main function */
main0
{
/* Open simulation results file */
if((simres=fopen("SIMRES.XLD", "w")) == NULL)
{
perror("fileopen failed");
exit(1);
}
for(loop1=0;loop1<outer;loop1++)
{
for(loop2=0;loop2<inner;loop2++)
{
for(k=0;k<runs;k++)
{
costsop = 0.0;
costshold = 0.0;
fileopen0;
initialize0;
coststm50;

/* Call function to open input and result files */
/* Call function to initialize arrays and other elements */
/* Call costs generation sub function to calculate yearly cost
and demand values and write results*/

for(aa=0;aa<years;aa++)
{
for(bb=0;bb<8;bb++)
{
fprintf(costdem, "%.2f\t", COSTARRAY[aa][bb]);
}
fprintf(costdem, "%.2f", DEMAND_ARRAY[aa]);
fprintf(costdem, "\n");
}
for(i=0;i<years;i++)
{
base_op0;
strat_op0;

/* Yearly iteration counter */

/* Call function to calculate reactive firm's operating parameters */
/* Call function to calculate proactive firm's operating parameters */

```

```

base_build0;
strat_build0;
calc_basecosts0;
calc_stratcosts0;
calc_discosts0;
write_results10;
}
RATARRAY[(outer*loop1)+(inner*loop2)+(k*runs)][0] = (T1ARRAY[years-1][0]/years)/(T1ARRAY[years-1][1]/years);
RATARRAY[(outer*loop1)+(inner*loop2)+(k*runs)][1] = (T2ARRAY[years-1][0]/years)/(T2ARRAY[years-1][1]/years);

write_results20;
fclose0;
}
fclose(simres);
}
}
graph10;
}

void fileopen(void)
{
if((oddat=fopen("ODDAT.XLD","w")) == NULL)
{
perror("fileopen failed");
exit(1);
}
if((sopsetdat=fopen("SOPSETDAT.XLD","w")) == NULL)
{
perror("fileopen failed");
exit(1);
}
if((bopsetdat=fopen("BOPSETDAT.XLD","w")) == NULL)
{
perror("fileopen failed");
}
}
}
}
}

/* Call function to assess reactive firm's building programme */
/* Call function to assess proactive firm's building programme */
/* Allocate total accrued costs in this year to reactive firm */
/* Allocate total accrued costs (yearly and cumulative) */
/* Write selected output (historical) to files */

/* Write additional results (summary) to data files */
/* Close data input and yearly result files */

/* Close simulation (summary) results */

/* Call graphics function to plot selected results */

/* End of main function */

/* Function to open all data input and output files */

```

```

exit(1);
}
if((costdem=fopen("COSTDEM.XLD","w")) == NULL)
{
perror("fileopen failed");
exit(1);
}
if((sfirmcost=fopen("SFRMCOST.XLD","w")) == NULL)
{
perror("fileopen failed");
exit(1);
}
if((bfirmcost=fopen("BFRMCOST.XLD","w")) == NULL)
{
perror("fileopen failed");
exit(1);
}
}

```

/ Function to close all data input files */*

```

void fileclose(void)
{
fclose(sopsetdat);
fclose(bopsetdat);
fclose(costdem);
fclose(sfirmcost);
fclose(bfirmcost);
fclose(oddat);
}

```

/ Function to read data input files, allocate values to relevant arrays
for use in the cost allocation functions, and initialize arrays */*

```

void initialize(void)
{

```



```

/*OPEN AND READ SCALE AND DESIGN LIFE FUNCTIONS*/
if((scaleinf=fopen("C:\\C600\\PAULJ\\LTIMES\\SCALE.TXT", "r")) == NULL)
{
    perror("fileopen failed");
    exit(1);
}
for(p=0;p<4;p++)
{
    fscanf(scaleinf, "%f", &SCALEFUNC[p]);
    fscanf(scaleinf, "%f", &SCALEFUNC[p+4]);
    fscanf(scaleinf, "%f", &SCALEFUNC[p+8]);
    fscanf(scaleinf, "%f", &SCALEFUNC[p+12]);
}
if((deslifeinf=fopen("C:\\C600\\PAULJ\\LTIMES\\DESLIFE.TXT", "r")) == NULL)
{
    perror("fileopen failed");
    exit(1);
}
for(p=0;p<4;p++)
{
    fscanf(deslifeinf, "%f", &DESLIFEFUNC[p]);
    fscanf(deslifeinf, "%f", &DESLIFEFUNC[p+4]);
    fscanf(deslifeinf, "%f", &DESLIFEFUNC[p+8]);
    fscanf(deslifeinf, "%f", &DESLIFEFUNC[p+12]);
}
if((oprats=fopen("C:\\C600\\PAULJ\\LTIMES\\OPRATS.TXT", "r")) == NULL)
{
    perror("fileopen failed");
    exit(1);
}
for(p=0;p<4;p++)
{
    fscanf(oprats, "%f", &OPRATS[p]);
    fscanf(oprats, "%f", &OPRATS[p+4]);
    fscanf(oprats, "%f", &OPRATS[p+8]);
    fscanf(oprats, "%f", &OPRATS[p+12]);
}

```

```

fscanf(oprats, "%f", &OPRATS[p+16]);
fscanf(oprats, "%f", &OPRATS[p+20]);
fscanf(oprats, "%f", &OPRATS[p+24]);
fscanf(oprats, "%f", &OPRATS[p+28]);
}
fclose(scaleinf);
fclose(deslifeinf);
fclose(oprats);
SUNITCOUNT[0][0] = 1;
SUNITCOUNT[1][0] = 2;
BUNITCOUNT[0][0] = 1;
BUNITCOUNT[1][0] = 2;
COSTCODE[0] = 1.0;
COSTCODE[1] = 1.1;
COSTCODE[2] = 1.2;
COSTCODE[3] = 1.3;
COSTCODE[4] = 2.0;
COSTCODE[5] = 2.1;
COSTCODE[6] = 2.2;
COSTCODE[7] = 2.3;

```

/ Initialize plant performance and status information arrays */*

```

for(p=0;p<years;p++)
{
for(i=0;i<12;i++)
{
T1ARRAY[p][i] = 0;
T2ARRAY[p][i] = 0;
BASE_COSTS[p][i] = 0;
STRAT_COSTS[p][i] = 0;
}
}

for(aa=0;aa<40;aa++)
{
for(bb=0;bb<12;bb++)
{

```

/ Initialize technology and firm specific cost result arrays */*

```

SOPSETARRAY[aa][bb] = 0;
BOPSETARRAY[aa][bb] = 0;
}
}
for(aa=0;aa<40;aa++)
{
for(bb=0;bb<years+1;bb++)
{
SUNITSTATUS[aa][bb] = 0;
BUNITSTATUS[aa][bb] = 0;
}
}

```

/ Initialize starting technology configurations for both firms (each set of parameters represents one item of plant) */*

```

SOPSETARRAY[0][0] = 1.01;
SOPSETARRAY[0][1] = 2.0;
SOPSETARRAY[0][2] = 1.0;
SOPSETARRAY[0][3] = 1000.0;
SOPSETARRAY[0][4] = 2.0;
SOPSETARRAY[0][5] = 20.0;
SOPSETARRAY[0][6] = 3.0;
SOPSETARRAY[0][7] = 1.0;
SOPSETARRAY[0][8] = 0.0;
SOPSETARRAY[0][9] = 1000.0;
SOPSETARRAY[0][10] = 1.0;
SUNITSTATUS[0][0] = 1.01;
SUNITSTATUS[0][1] = 2.0;
SUNITCOUNT[0][1] = 1.0;

SOPSETARRAY[1][0] = 1.02;
SOPSETARRAY[1][1] = 2.0;
SOPSETARRAY[1][2] = 1.0;
SOPSETARRAY[1][3] = 1000.0;
SOPSETARRAY[1][4] = 3.0;

```

SOPSETARRAY[1][5] = 25.0;
SOPSETARRAY[1][6] = 7.0;
SOPSETARRAY[1][7] = 4.0;
SOPSETARRAY[1][8] = 0.0;
SOPSETARRAY[1][9] = 1000.0;
SOPSETARRAY[1][10] = 1.0;
SUNITSTATUS[1][0] = 1.02;
SUNITSTATUS[1][1] = 2.0;
SUNITCOUNT[0][1] = 2.0;

SOPSETARRAY[2][0] = 2.01;
SOPSETARRAY[2][1] = 2.0;
SOPSETARRAY[2][2] = 2.0;
SOPSETARRAY[2][3] = 500;
SOPSETARRAY[2][4] = 1.0;
SOPSETARRAY[2][5] = 25.0;
SOPSETARRAY[2][6] = 20.0;
SOPSETARRAY[2][7] = 5.0;
SOPSETARRAY[2][8] = 5.0;
SOPSETARRAY[2][9] = 7000.0;
SOPSETARRAY[2][10] = 1.0;
SUNITSTATUS[2][0] = 2.01;
SUNITSTATUS[2][1] = 2.0;
SUNITCOUNT[1][1] = 1.0;

SOPSETARRAY[3][0] = 2.02;
SOPSETARRAY[3][1] = 2.0;
SOPSETARRAY[3][2] = 2.0;
SOPSETARRAY[3][3] = 1200;
SOPSETARRAY[3][4] = 1.0;
SOPSETARRAY[3][5] = 25.0;
SOPSETARRAY[3][6] = 8.0;
SOPSETARRAY[3][7] = 7.0;
SOPSETARRAY[3][8] = 0.0;
SOPSETARRAY[3][9] = 8050.0;
SOPSETARRAY[3][10] = 1.0;

```
SUNITSTATUS[3][0] = 2.02;
SUNITSTATUS[3][1] = 2.0;
SUNITCOUNT[1][1] = 2.0;
```

```
BOPSETARRAY[0][0] = 1.01;
BOPSETARRAY[0][1] = 2.0;
BOPSETARRAY[0][2] = 1.0;
BOPSETARRAY[0][3] = 2300.0;
BOPSETARRAY[0][4] = 1.0;
BOPSETARRAY[0][5] = 25.0;
BOPSETARRAY[0][6] = 8.0;
BOPSETARRAY[0][7] = 7.0;
SOPSETARRAY[3][8] = 0.0;
BOPSETARRAY[0][9] = 26400.0;
BOPSETARRAY[0][10] = 1.0;
BUNITSTATUS[0][0] = 1.01;
BUNITSTATUS[0][1] = 2.0;
BUNITCOUNT[0][1] = 1.0;
}
```

```
/* Function to calculate costs accrued by reactive firm */
```

```
/* First section calculates accrued capital cost expenditure */
```

```
/* Search technology base array for plants currently under construction */
```

```
void calc_basecosts(void)
{
for(aa=0;aa<40;aa++)
{
if(BOPSETARRAY[aa][1] == 1.0)
{
codenum = BOPSETARRAY[aa][2];
codenum += 0.0;
for(bb=0;bb<8;bb++)
{
if(COSTCODE[bb] == codenum)
{
temp = bb;
ii = (i+1) - BOPSETARRAY[aa][6];

```

```

/* Access cost element for this technology */
tempcost = (COSTARRAY[ij][temp]/1000)*BOPSETARRAY[aa][3];

/* Identify technology type & access constant term in function */
typecode = (BOPSETARRAY[aa][2]*3) + (BOPSETARRAY[aa][2]-1);

/* Adjust for scale of unit */
tempcost = tempcost*(((pow(SCALEFUNC[typecode-3]*BOPSETARRAY[aa][3],3)) + (pow(SCALEFUNC[typecode-2]*BOPSETARRAY[aa][3],2)) + (SCALEFUNC[typecode-1]*BOPSETARRAY[aa][3]) + (SCALEFUNC[typecode]))/BOPSETARRAY[aa][3]);

/* Adjust for design life */
tempcost = tempcost*((pow(DESLEIFUNC[typecode-3]*BOPSETARRAY[aa][5],3)) + (pow(DESLEIFUNC[typecode-2]*BOPSETARRAY[aa][5],2)) + (DESLEIFUNC[typecode-1]*BOPSETARRAY[aa][5]) + DESLEIFUNC[typecode]);
BASE_COSTS[i][0] += tempcost/BOPSETARRAY[aa][4];
}
}
}

for(aa=0;aa<40;aa++)
{
if(BUNITSTATUS[aa][i+1] == 2.0)
{
codenum = floor(BUNITSTATUS[aa][0]);
codenum += 0.1;
code = BUNITSTATUS[aa][0];
for(bb=0;bb<8;bb++)
{
if(COSTCODE[bb] == codenum)
{
temp = bb;
}
}
}
}
}

/* Calculate accrued operating costs */

/* Search operating set array for plant utilisation information */

```

```

tempcost = COSTARRAY[i][temp];
for(cc=0;cc<40;cc++)
{
if(BOPSETARRAY[cc][0] == code)
{
/* Adjust for capacity of plant */
tempcost = tempcost*(BOPSETARRAY[cc][11]/1000);

/* Identify technology type & access correct terms in adjustment array */
typecode = ((BOPSETARRAY[cc][2]-1) + (3*(BOPSETARRAY[cc][2]-1)));

/* Adjust for age of plant */
tempcost = tempcost*((pow(OPRATS[typecode]*BOPSETARRAY[cc][6],3))+(pow(OPRATS[typecode+1]*
BOPSETARRAY[cc][6],2))+(OPRATS[typecode+2]*BOPSETARRAY[cc][6])+(OPRATS[typecode+3]));

/* Adjust for size of plant */
tempcost = tempcost*((pow(OPRATS[typecode+4]*BOPSETARRAY[cc][3]/100,3))+(pow(OPRATS[typecode+5]*
BOPSETARRAY[cc][3]/100,2))+(OPRATS[typecode+6]*BOPSETARRAY[cc][3]/100)+(OPRATS[typecode+7]));

/* Adjust for years since construction (absolute age ) of plant */
tempcost = tempcost*((pow(OPRATS[typecode+8]*BOPSETARRAY[cc][7],3))+(pow(OPRATS[typecode+9]*
BOPSETARRAY[cc][7],2))+(OPRATS[typecode+10]*BOPSETARRAY[cc][7])+(OPRATS[typecode+11]));

/* Adjust for operating age of plant (years usage) */
tempcost = tempcost*((pow(OPRATS[typecode+12]*BOPSETARRAY[cc][9]/1000,3))+(pow(OPRATS[typecode+13]*
BOPSETARRAY[cc][9]/1000,2))+(OPRATS[typecode+14]*BOPSETARRAY[cc][9]/1000)+(OPRATS[typecode+15]));
BASE_COSTS[i][1] += tempcost;
}
}
}

```

```

    }
    }
}

for(aa=0;aa<40;aa++)
{
    if(BUNITSTATUS[aa][i+1] == 3.0)
    {
        codenum = floor(BUNITSTATUS[aa][0]);
        codenum += 0.2;
        for(bb=0;bb<8;bb++)
        {
            if(COSTCODE[bb] == codenum)
            {
                temp = bb;
                BASE_COSTS[i][2] += COSTARRAY[i][temp]; /* Assess cost element for those units built but not in use */
            }
        }
    }
}

/* Summate costs for reactive firm and write results to file */

BASE_COSTS[j][3] = BASE_COSTS[i][0]+BASE_COSTS[i][1]+BASE_COSTS[i][2];
for(aa=0;aa<40;aa++)
{
    fprintf(bopsetdat, "%.2f\t",BOPSETARRAY[aa][6]);
}
fprintf(bopsetdat, "\n");
}

void calc_stratcosts(void)
{
    for(aa=0;aa<40;aa++)

```

*/*Calculate accrued dormancy costs*/*

/ Identify dormant plant from usage array */*

/ Assess cost element for those units built but not in use */*

/ Summate costs for reactive firm and write results to file */*

/ Calculate accrued costs for proactive firm */*

/ Algorithm identical to that used for reactive firm */*


```

{
if(SOPSETARRAY[aa][1] == 1.0)
{
codenum = SOPSETARRAY[aa][2];
codenum += 0.0;
for(bb=0;bb<8;bb++)
{
if(COSTCODE[bb] == codenum)
{
temp = bb;
ii = (i+1) - SOPSETARRAY[aa][6];
tempcost = (COSTARRAY[ii][temp]/1000)*SOPSETARRAY[aa][3];
typecode = (SOPSETARRAY[aa][2]*3) + (SOPSETARRAY[aa][2]-1);
tempcost = tempcost*((pow(SCALEFUNC[typecode-3]*SOPSETARRAY[aa][3],3)) + (pow(SCALEFUNC[typecode-
2]*SOPSETARRAY[aa][3],2)) + (SCALEFUNC[typecode-
1]*SOPSETARRAY[aa][3]) + (SCALEFUNC[typecode]))/SOPSETARRAY[aa][3]);
tempcost = tempcost*((pow(DESLIFEFUNC[typecode-3]*SOPSETARRAY[aa][5],3)) + (pow(DESLIFEFUNC[typecode-
2]*SOPSETARRAY[aa][5],2)) + (DESLIFEFUNC[typecode-1]*SOPSETARRAY[aa][5]) + DESLIFEFUNC[typecode]);
STRAT_COSTS[j][0] += tempcost/SOPSETARRAY[aa][4];
if(SOPSETARRAY[aa][2] == 2.0)
{
costshold += tempcost/SOPSETARRAY[aa][4];
}
}
}
}
}
for(aa=0;aa<40;aa++)
{
if(SUNITSTATUS[aa][i+1] == 2.0)
{
codenum = floor(SUNITSTATUS[aa][0]);
codenum += 0.1;
code = SUNITSTATUS[aa][0];
for(bb=0;bb<8;bb++)
{

```

```

if(COSTCODE[bb] == codenum)
{
temp = bb;
tempcost = COSTARRAY[i][temp];
for(cc=0;cc<40;cc++)
{
if(SOPSETARRAY[cc][0] == code)
{
tempcost = tempcost*(SOPSETARRAY[cc][11]/1000);
typecode = ((SOPSETARRAY[cc][2]-1) + (3*(SOPSETARRAY[cc][2]-1)));
tempcost = tempcost*((pow(OPRATS[typecode]*SOPSETARRAY[cc][6],3)) + (pow(OPRATS[typecode+1]*
SOPSETARRAY[cc][6],2)) + (OPRATS[typecode+2]*SOPSETARRAY[cc][6]) + (OPRATS[typecode+3]));
tempcost = tempcost*((pow(OPRATS[typecode+4]*SOPSETARRAY[cc][3]/100,3)) + (pow(OPRATS[typecode+5]*
SOPSETARRAY[cc][3]/100,2)) + (OPRATS[typecode+6]*SOPSETARRAY[cc][3]/100) + (OPRATS[typecode+7]));
tempcost = tempcost*((pow(OPRATS[typecode+8]*SOPSETARRAY[cc][7],3)) + (pow(OPRATS[typecode+9]*
SOPSETARRAY[cc][7],2)) + (OPRATS[typecode+10]*SOPSETARRAY[cc][7]) + (OPRATS[typecode+11]));
tempcost = tempcost*((pow(OPRATS[typecode+12]*SOPSETARRAY[cc][9]/1000,3)) + (pow(OPRATS[typecode+13]*
SOPSETARRAY[cc][9]/1000,2)) + (OPRATS[typecode+14]*SOPSETARRAY[cc][9]/1000) + (OPRATS[typecode+15]));
STRAT_COSTS[i][1] += tempcost;
if(SOPSETARRAY[cc][2] == 1.0 && COSTARRAY[i][1] > COSTARRAY[i][5])
{
costsop += tempcost - (tempcost/COSTARRAY[i][1])*COSTARRAY[i][5];
}
}
}
}
}
}
for(aa=0;aa<40;aa++)
{
if(SUNITSTATUS[aa][i+1] == 3.0)
{
codenum = floor(SUNITSTATUS[aa][0]);
codenum += 0.2;
for(bb=0;bb<8;bb++)

```

```

{
if(COSTCODE[bb] == codenum)
{
temp = bb;
STRAT_COSTS[i][2] += COSTARRAY[i][temp];
for(cc=0;cc<40;cc++)
{
if(SOPSETARRAY[cc][0] == SUNITSTATUS[aa][0] && SOPSETARRAY[cc][2] == 2.0)
{
costshold += COSTARRAY[i][temp];
}
}
}
}
STRAT_COSTS[i][3] = STRAT_COSTS[i][0]+STRAT_COSTS[i][1]+STRAT_COSTS[i][2];
for(aa=0;aa<30;aa++)
{
fprintf(sopsetdat, "%2f %2f",SOPSETARRAY[aa][1],SOPSETARRAY[aa][6]);
}
fprintf(sopsetdat, "\n");
}

void calc_discosts(void)
{
n = i;
if(i==0)
{
BASE_COSTS[i][4] = BASE_COSTS[i][3];
STRAT_COSTS[i][4] = STRAT_COSTS[i][3];
}
else
{

```

/ Calculate cumulative and discounted costs & write all cost results to files */*

/ Calculate cumulative costs */*

```

BASE_COSTS[i][4] = BASE_COSTS[i-1][4] + BASE_COSTS[i][3];
STRAT_COSTS[i][4] = STRAT_COSTS[i-1][4] + STRAT_COSTS[i][3];
}
BASE_COSTS[i][5] = BASE_COSTS[i][4]/pow(1+rate,n); /* Calculate discounted cumulative costs */
STRAT_COSTS[i][5] = STRAT_COSTS[i][4]/pow(1+rate,n);
for(aa=0;aa<8;aa++)
{
    fprintf(bfirmcost, "%.2f\t",BASE_COSTS[i][aa]);
}
fprintf(bfirmcost, "\n");
for(aa=0;aa<8;aa++)
{
    fprintf(sfirmcost, "%.2f\t",STRAT_COSTS[i][aa]);
}
fprintf(sfirmcost, "\n");
}

void write_results1(void)
{
    fprintf(oddat, "%.2f\t%.2f\t%.2f\t",scapacity,savail,bcapacity,bavail);
    fprintf(oddat, "%.2f\n",STRAT_COSTS[j][5] - BASE_COSTS[j][5]);
}

/* Function to write year on year results to data output files */

void write_results2(void)
{
    if((sunitdat=fopen("SUNITDAT.XLD", "w")) == NULL)
    {
        perror("fileopen failed");
        exit(1);
    }
    if((bunitdat=fopen("BUNITDAT.XLD", "w")) == NULL)
    {
        perror("fileopen failed");
        exit(1);
    }
}

/* Function to write simulation level results to data output files */

```

```

}
if((ratiodat=fopen("RATIODAT.XLD","w")) == NULL)
{
perror("fileopen failed");
exit(1);
}
for(aa=0;aa < years + 1;aa++)
{
for(bb=0;bb < 30;bb++)
{
fprintf(bunitdat,"%%.2f ",BUNITSTATUS[bb][aa]);
}
fprintf(bunitdat,"\n");
}
for(aa=0;aa < years + 1;aa++)
{
for(bb=0;bb < 30;bb++)
{
fprintf(sunitdat,"%%.2f ",SUNITSTATUS[bb][aa]);
}
}
fprintf(sunitdat,"\n");
}
for(aa=0;aa < years;aa++)
{
for(bb=0;bb < 8;bb++)
{
fprintf(ratiodat,"%%.2ft",T1ARRAY[aa][bb]);
fprintf(ratiodat,"%%.2ft",T2ARRAY[aa][bb]);
fprintf(ratiodat,"%%.2ft",SYSARRAY[aa][bb]);
}
}
fprintf(ratiodat,"\n");
}
fprintf(simres,"%%.2ft%.2ft%.2ft",RATARRAY[k][0],RATARRAY[k][1],BASE_COSTS[i-1][4]-STRAT_COSTS[i-1][4]);
fclose(sunitdat);
fclose(bunitdat);
fclose(ratiodat);

```

/ Graphics function to depict final simulation cost function trends */*

```

}
void graph1(void)
{
    _setvideomode(_DEFAULTMODE);
    printf("\n\nFinal simulation cost functions shown...");
    getch();
    _setvideomode(_VRES16COLOR);
    _setwindow(0,0,640,480);
    _rectangle(_GBORDER,10,10,630,460);
    _setviewport(0,0,640,480);
    _clearscreen(_GVIEWPORT);
    for(i=0;i<years;i++)
    {
        for(j=0;j<5;j++)
        {
            g1categs[j][i]=i;
        }
    }
    for(i=0;i<years;i++)
    {
        g1vals[0][i]=COSTARRAY[i][0];
        g1vals[1][i]=COSTARRAY[i][4];
        g1vals[2][i]=COSTARRAY[i][1];
        g1vals[3][i]=COSTARRAY[i][5];
        g1vals[4][i]=SYSARRAY[i][0];
    }
    _pg_initchart0;
    _pg_defaultchart(&env,_PG_SCATTERCHART,_PG_POINTANDLINE);
    strcpy(env.xaxis.axisitle.title,"YEAR");
    strcpy(env.yaxis.axisitle.title,"COST");
    _pg_chartsctterms(&env,(float _far *)g1categs,(float _far *)g1vals,5,years,g1labels);
    getch();
    _setvideomode(_DEFAULTMODE);
}

```

BUILD

'C' Program to assess the need for technology set expansion or replacement as part of the LTIME program

Paul Jeffrey

INTA/IERC Cranfield Institute of Technology 1992

```
#include <bios.h>
#include <string.h>
#include <stdio.h>
#include <process.h>
#include <graph.h>
#include <stdlib.h>
#include <conio.h>
#include <pgchart.h>
#include <math.h>
#define years 50

float DEMAND_ARRAY[years];
float COSTARRAY[years+1][8];
int i, l;
float SOPSETARRAY[40][12];
float SUNITSTATUS[40][years+1];
float SUNITCOUNT[2][2];
float tempadd[10];
float mintec1, mintec2, codenum;
float scapacity, demand, test, savail;
int aa,bb,cc,dd,ee,select;
char name[17];

/* Preprocessor define and include statements */

/* Counter and array declarations */
```

/ Main function: searches technology set status arrays to determine what units to build */*

```
strat_build0
{
for(aa=0;aa<40;aa++)
{
test = SOPSETARRAY[aa][5] - (SOPSETARRAY[aa][4]+1);      /* Search array */
if((SOPSETARRAY[aa][6] > 1 && SOPSETARRAY[aa][6] == test && SOPSETARRAY[aa][1] == 2)
{
bb=0;
/* If an item of plant is coming to the end of its
lifecycle begin construction of a replacement */

while(SOPSETARRAY[bb][0] != 0)
{
bb +=1;
}
/* Transfer information for replacement plant to new position */
SOPSETARRAY[bb][1] = 1;
SOPSETARRAY[bb][2] = SOPSETARRAY[aa][2];
SOPSETARRAY[bb][3] = SOPSETARRAY[aa][3];
SOPSETARRAY[bb][4] = SOPSETARRAY[aa][4];
SOPSETARRAY[bb][5] = SOPSETARRAY[aa][5];
for(cc=0;cc<2;cc++)
{
if(SUNITCOUNT[cc][0] == SOPSETARRAY[bb][2])      /* Initialize relevant array settings */
{
SOPSETARRAY[bb][0] = SUNITCOUNT[cc][0] + ((SUNITCOUNT[cc][1] + 1)/100);
SUNITCOUNT[cc][1] += 1;
}
}
dd=0;
while(SUNITSTATUS[dd][0] != 0)
{
dd +=1;
}
SUNITSTATUS[dd][0] = SOPSETARRAY[bb][0];
SUNITSTATUS[dd][i+1] = 1;
}
```



```

    }
}

for(aa=0;aa<40;aa++)
{
    if(SOPSETARRAY[aa][6] >= SOPSETARRAY[aa][5] && SOPSETARRAY[aa][1] == 2)
    {
        SOPSETARRAY[aa][1] = 3;
        SOPSETARRAY[aa][10] = 0;

        codenum = SOPSETARRAY[aa][0];
        for(bb=0;bb<40;bb++)
        {
            if(SUNITSTATUS[bb][0] == codenum)
            {
                SUNITSTATUS[bb][i+1] = 4;
            }
        }
    }
}

for(aa=0;aa<40;aa++)
{
    if(SOPSETARRAY[aa][1] == 1 && SOPSETARRAY[aa][6] > SOPSETARRAY[aa][4])
    {
        SOPSETARRAY[aa][1] = 2;
    }
}

```

/ When unit reaches the end of its design life, increment markers
to take it out of the operating order */*

OPERATE

Program to sort plant into an operating order and apply costs according to usage as part of LTIME program

Paul Jeffrey

INTA/IERC Cranfield Institute of Technology 1992

```
#include <bios.h>
#include <string.h>
#include <stdio.h>
#include <process.h>
#include <graph.h>
#include <stdlib.h>
#include <conio.h>
#include <pgchart.h>
#include <math.h>
#define years 50

float DEMAND_ARRAY[years];
float COSTARRAY[years+1][8];
int i, k;
float SOPSETARRAY[40][12];

/* Preprocessor define and include statements */

/* Array and counter declarations */

/* Listing for the technology parameter array. SOPSETARRAY
0 Overall code #
1 Not built/being built/scrapped (0/1/2/3)
2 Technology type (1,2,3,4)
3 Size
4 Lead time
5 Design lifetime
6 Age from first build year
7 Cumulative years op
8 Cumulative years dorm
```

9 Total output
10 Availability marker */

```
float SUNITSTATUS[40][years+1];
```

*/*Listing of plant status code values used in SUNITSTATUS*

*'0' Not initiated
'1' Being constructed
'2' Constructed / active
'3' Constructed / dormant
'4' Scrapped */*

```
float SUNITCOUNT[2][2];  
float tempadd[10];  
float mintec1, mintec2, codenum;  
float scapacity, demand, test, savail;  
int aa,bb,cc,dd,ee,select;  
char name[17];
```

/ Misc variable declarations */*

/ Main function: Determines operating order and brings plant on line
until demand is fulfilled */*

```
strat_op0  
{  
savail = 0;  
for(aa=0;aa<40;aa++)  
{  
codenum = SOPSETARRAY[aa][0];  
if(SOPSETARRAY[aa][1] != 2)  
{  
SOPSETARRAY[aa][10] = 0;  
}  
else  
{  
SOPSETARRAY[aa][10] = 1;  
savail += SOPSETARRAY[aa][3];
```

/ Determine availability of plant and update markers in arrays */*

```

    }
}

/* Select which units to operate and update counters in array
   (N.B. Alternative criteria can be used) */

/* Order items of plant according to operating cost levels */
if(COSTARRAY[i][1] < COSTARRAY[i][5])
{
    mintec1 = 1.0;
    mintec2 = 2.0;
}
else
{
    mintec1 = 2.0;
    mintec2 = 1.0;
}

for(cc=0;cc<80;cc++)
{
    for (aa=1;aa<41;aa++)
    {
        if(SOPSETARRAY[aa][10] == 1)
        {
            for(dd=0;dd<11;dd++)
            {
                tempadd[dd] = SOPSETARRAY[aa-1][dd];
                SOPSETARRAY[aa-1][dd] = SOPSETARRAY[aa][dd];
                SOPSETARRAY[aa][dd] = tempadd[dd];
            }
        }
    }
}

/* Algorithm to sort array into youngest---oldest equipment within the cost criteria groupings determined above (i.e. an operating order)*/
for(cc=0;cc<80;cc++)
{
    for (aa=1;aa<41;aa++)

```



```

if(scapacity < demand)
{
  SOPSETARRAY[I][11] = SOPSETARRAY[I][3];
}
else
{
  /* Set marker to indicate whether total or partial capacity has been used */
  SOPSETARRAY[I][11] = SOPSETARRAY[I][3] - (scapacity - demand);
}
SOPSETARRAY[I][7] += 1;
SOPSETARRAY[I][9] += SOPSETARRAY[I][3];
codenum = SOPSETARRAY[I][0];
for(aa=0;aa<40;aa++)
{
  if(SUNITSTATUS[aa][0] == codenum)
  {
    SUNITSTATUS[aa][i+1] = 2;
  }
}
}
}

for(aa=0;aa<40;aa++)
{
  if(SOPSETARRAY[aa][10] == 1)
  {
    codenum = SOPSETARRAY[aa][0];
    for(bb=0;bb<40;bb++)
    {
      if(SUNITSTATUS[bb][0] == codenum && SUNITSTATUS[bb][i+1] != 2)
      {
        SOPSETARRAY[aa][8] += 1;
        SUNITSTATUS[bb][i+1] = 3;
      }
    }
  }
}
}

```

/ Update markers for remaining dormant units */*

```

}
for(aa=0;aa<40;aa++)
{
  if(SOPSETARRAY[aa][1] == 1 || SOPSETARRAY[aa][1] == 2)
  {
    SOPSETARRAY[aa][6] += 1;
  }
}
for(bb=0;bb<40;bb++)
{
  if(i != 0)
  {
    if(SUNITSTATUS[bb][0] != 0 && SUNITSTATUS[bb][i+1] == 0)
    {
      SUNITSTATUS[bb][i+1] = SUNITSTATUS[bb][i];
    }
  }
}
}

```

/ Increase all plant ages by 1 year & change status indicators */*

```
/*
```

COSTFUNC

'C' Program to evaluate the costs of various elements of each technologies cost regime (capital operating etc) as part of LTIME program

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```
*/  
  
#include <bios.h>  
#include <string.h>  
#include <stdio.h>  
#include <process.h>  
#include <graph.h>  
#include <stdlib.h>  
#include <conio.h>  
#include <pgchart.h>  
#include <math.h>  
#define FALSE 0  
#define TRUE 1  
#define LABEL 1  
#define BLUE 1  
#define RED 4  
#define YELLOW 14  
#define MAGENTA 5  
#define GREEN 2  
#define years 50  
#define const 0.0000305185091  
void init_xvalref(void);  
float rand_gen(float rangmax, float rangmin);  
void calc_ccosts(void);  
void calc_ocosts(void);  
void calc_dcosts(void);  
  
/* Sub function declarations */
```



```
void calc_variables(void);
void regime_switch(void);
void calc_demand(void);
```

```
/* Suffix Codes for cost element variables
```

```
MT = Macro Turbulence  
X3 = Cubed Element Of Cost Function  
X2 = Squared Element Of Cost Function  
X = Linear Element Of Cost Function  
CON = Constant Element Of Cost Function  
TF = Turbulence Factor  
FF = Frequency Factor  
FT = Frequency Of Turbulence Factor
```

```
N.B. See description of cost generation technique in text for further details.  
*/
```

```
/* Variable declarations */
```

```
float CC1MT, CC1X3, CC1X2, CC1X, CC1CON, CC1TF, CC1FF, CC1FT;  
float CC2MT, CC2X3, CC2X2, CC2X, CC2CON, CC2TF, CC2FF, CC2FT;  
float OC1MT, OC1X3, OC1X2, OC1X, OC1CON, OC1TF, OC1FF, OC1FT;  
float OC2MT, OC2X3, OC2X2, OC2X, OC2CON, OC2TF, OC2FF, OC2FT;  
float CC1MTMAX, CC1MTMIN, CC1X3MAX, CC1X3MIN;  
float CC1X2MAX, CC1X2MIN, CC1XMAX, CC1XMIN;  
float CC1CONMAX, CC1CONMIN, CC1TFMAX, CC1TFMIN;  
float CC1FF, CC1FTMAX, CC1FTMIN;  
float CC2MTMAX, CC2MTMIN, CC2X3MAX, CC2X3MIN;  
float CC2X2MAX, CC2X2MIN, CC2XMAX, CC2XMIN;  
float CC2CONMAX, CC2CONMIN, CC2TFMAX, CC2TFMIN;  
float CC2FF, CC2FTMAX, CC2FTMIN;  
float OC1MTMAX, OC1MTMIN, OC1X3MAX, OC1X3MIN;  
float OC1X2MAX, OC1X2MIN, OC1XMAX, OC1XMIN;  
float OC1CONMAX, OC1CONMIN, OC1TFMAX, OC1TFMIN;
```

```

float OC1FF, OC1FTMAX, OC1FTMIN;
float OC2MTMAX, OC2MTMIN, OC2X3MAX, OC2X3MIN;
float OC2X2MAX, OC2X2MIN, OC2XMAX, OC2XMIN;
float OC2CONMAX, OC2CONMIN, OC2TFMAX, OC2TFMIN;
float OC2FF, OC2FTMAX, OC2FTMIN;
float TICCOST, T2CCOST, T1OCCOST, T2OCCOST;
float switche1jump1, switche2jump1;
int switcho1mark1, switcho2mark1, switcho1, switcho2, mark1, switchdmark1;
float switcho1jump1, switcho2jump1, switchdjump1;
float DMT, DX3, DX2, DX, DCON, DTF, DFF, DFT;
float DMTMAX, DMTMIN, DX3MAX, DX3MIN;
float DX2MAX, DX2MIN, DXMAX, DXMIN;
float DCONMAX, DCONMIN, DTFMAX, DTFMIN;
float DFF, DFTMAX, DFTMIN;
float DEMAND;
float _far DEMAND_ARRAY[years];
float _far COSTARRAY[years+1][8];
double _far T1ARRAY[years][4];
double _far T2ARRAY[years][4];
double XVALREF[years][5];
float u1, u2, b, s, rnd, diff;
int kc=0, lc=0, ko=0, lo=0, dc=0, mc=0, nc=0, pc=0, jc;
int i, k, j, indi;
int loop1, loop2;
unsigned seed;

/* Main function: Calculates values for cost elements and resulting cost
parameters using a bounded stochastic technique */

coststm50
{
/* Initialise cost and demand variable Maxima and Minima */

CC1MTMAX=0.0; CC1MTMIN=0.0; CC1X3MAX=0.0; CC1X3MIN=0.0;
CC1X2MAX=0.0; CC1X2MIN=0.0; CC1XMAX=0.0; CC1XMIN=0.0;
CC1CONMAX=8000-(loop2*300); CC1CONMIN=8000-(loop2*300); CC1TFMAX=0.0; CC1TFMIN=0.0;

```

```

CC1FF=0.0; CC1FTMAX=0.0; CC1FTMIN=0.0;
CC2MTMAX=0.0; CC2MTMIN=0.0; CC2X3MAX=0; CC2X3MIN=0;
CC2X2MAX=0.0; CC2X2MIN=0.0; CC2XMAX=0.0; CC2XMIN=0.0;
CC2CONMAX=4000+(300*loop1); CC2CONMIN=4000+(300*loop1); CC2TFMAX=0.0; CC2TFMIN=0.0;
CC2FF=0.0; CC2FTMAX=0.0; CC2FTMIN=0.0;
OC1MTMAX=0.3; OC1MTMIN=0.25; OC1X3MAX=3.0; OC1X3MIN=2.0;
OC1X2MAX=4.0; OC1X2MIN=2.0; OC1XMAX=12.0; OC1XMIN=5.0;
OC1CONMAX=1800; OC1CONMIN=1800; OC1TFMAX=600.0; OC1TFMIN=500.0;
OC1FF=0.3; OC1FTMAX=0.8; OC1FTMIN=0.7;
OC2MTMAX=0.4; OC2MTMIN=0.3; OC2X3MAX=2.0; OC2X3MIN=2.0;
OC2X2MAX=2.0; OC2X2MIN=2.0; OC2XMAX=8.0; OC2XMIN=3.0;
OC2CONMAX=2000; OC2CONMIN=2000; OC2TFMAX=300.0; OC2TFMIN=250.0;
OC2FF=0.8; OC2FTMAX=0.65; OC2FTMIN=0.55;
DMTMAX=0.0; DMTMIN=0.0; DX3MAX=0.0; DX3MIN=0.0;
DX2MAX=0.0; DX2MIN=0.0; DXMAX=0.0; DXMIN=0.0;
DCONMAX=2000; DCONMIN=2000; DTFMAX=0.0; DTFMIN=0.0;
DFF=0.0; DFTMAX=0.0; DFTMIN=0.0;

for(pc=0;pc<years;pc++)
{
    regime_switch();
    calc_variables();

    calc_ccosts();
    calc_ocosts();
    calc_dcosts();
    calc_demand();
}

/* Call function to apply a cost 'regime switch' to any cost element */
/* Call function to determine the variables used in the cost calculation
   (random values between relevant max and min bounds */
/* Call function to evaluate capital costs for each technology */
/* Call function to evaluate operating costs for each technology */
/* Call function to evaluate dormancy costs for each technology */
/* Call function to evaluate demand levels */

/* Function to determine regime switch */

void regime_switch(void)
{
    switch1mark1 = -1;

```

```

switchc1jump1 = -1;
switchc2mark1 = -1;
switchc2jump1 = -1;
switcho1mark1 = 15;
switcho1jump1 = 1/0.8;
switcho2mark1 = -1;
switcho2jump1 = -1;
switchdmark1 = -1;
switchdjump1 = -1;
if(pc == switchdmark1)
{
    DCONMAX *= switchdjump1;
    DCONMIN *= switchdjump1;
}
if(pc == switchc1mark1)
{
    CC1CONMAX *= switchc1jump1;
    CC1CONMIN *= switchc1jump1;
}
if(pc == switchc2mark1)
{
    CC2CONMAX *= switchc2jump1;
    CC2CONMIN *= switchc2jump1;
}
if(pc == switcho1mark1)
{
    OC1CONMAX *= switcho1jump1;
    OC1CONMIN *= switcho1jump1;
}
if(pc == switcho2mark1)
{
    OC2CONMAX *= switcho2jump1;
    OC2CONMIN *= switcho2jump1;
}
}

```

/ Function to initialize the x value reference to reflect the frequency factor. */*

```
void init_xvalref(void)
{
    for(jc=0;jc<years;jc++)
    {
        XVALREF[jc][0] = jc*CC1FF;
        XVALREF[jc][1] = jc*CC2FF;
        XVALREF[jc][2] = jc*OC1FF;
        XVALREF[jc][3] = jc*OC2FF;
        XVALREF[jc][4] = jc*DFF;
    }
}
```

/ Function to attribute a value to each component of the cost generation equation.
Accesses random number generator and bounds declared in variable declaration section (above) */*

```
void calc_variables(void)
{
    seed = (k*years)+pc;
    srand(seed);
    indi = 0;
    CC1MT = rand_gen(CC1MTMAX,CC1MTMIN);
    CC2MT = rand_gen(CC2MTMAX,CC2MTMIN);
    CC1X3 = rand_gen(CC1X3MAX,CC1X3MIN);
    CC1X2 = rand_gen(CC1X2MAX,CC1X2MIN);
    CC1X = rand_gen(CC1XMAX,CC1XMIN);
    CC1CON = rand_gen(CC1CONMAX,CC1CONMIN);
    CC1TF = rand_gen(CC1TFMAX,CC1TFMIN);
    CC1FT = rand_gen(CC1FTMAX,CC1FTMIN);
    CC2X3 = rand_gen(CC2X3MAX,CC2X3MIN);
    CC2X2 = rand_gen(CC2X2MAX,CC2X2MIN);
    CC2X = rand_gen(CC2XMAX,CC2XMIN);
    CC2CON = rand_gen(CC2CONMAX,CC2CONMIN);
}
```

/ Use years value and simulation run value to determine seed for random number generator */
/* Call random number generator function (internally defined 'c' math function) */
/* Set counter for random number algorithm to 0 */*

```

CC2TF = rand_gen(CC2TFMAX,CC2TFMIN);
CC2FT = rand_gen(CC2FTMAX,CC2FTMIN);
OC1MT = rand_gen(OC1MTMAX,OC1MTMIN);
OC2MT = rand_gen(OC2MTMAX,OC2MTMIN);
OC1X3 = rand_gen(OC1X3MAX,OC1X3MIN);
OC1X2 = rand_gen(OC1X2MAX,OC1X2MIN);
OC1X = rand_gen(OC1XMAX,OC1XMIN);
OC1CON = rand_gen(OC1CONMAX,OC1CONMIN);
OC1TF = rand_gen(OC1TFMAX,OC1TFMIN);
OC1FT = rand_gen(OC1FTMAX,OC1FTMIN);
OC2X3 = rand_gen(OC2X3MAX,OC2X3MIN);
OC2X2 = rand_gen(OC2X2MAX,OC2X2MIN);
OC2X = rand_gen(OC2XMAX,OC2XMIN);
OC2CON = rand_gen(OC2CONMAX,OC2CONMIN);
OC2TF = rand_gen(OC2TFMAX,OC2TFMIN);
OC2FT = rand_gen(OC2FTMAX,OC2FTMIN);
DX3 = rand_gen(DX3MAX,DX3MIN);
DX2 = rand_gen(DX2MAX,DX2MIN);
DX = rand_gen(DXMAX,DXMIN);
DCON = rand_gen(DCONMAX,DCONMIN);
DIF = rand_gen(DIFMAX,DIFMIN);
DFT = rand_gen(DFTMAX,DFTMIN);
DMT = rand_gen(DMTMAX,DMTMIN);
}

```

/ Sequentially call random number algorithm for each cost equation variable */*
/ Pass the upper and lower bound values as arguments to function */*

/ Random number generator function and conversion routine to scale result into variable range.*
*Takes maximum and minimum bounds as arguments */*

```

float rand_gen(float rangmax,float rangmin)
{
if (indi == 1)
{
md = b*u2;
}
else

```

```

{
ll: u1 = 2*(const*rand()-1);
u2 = 2*(const*rand()-1);
s = (u1*u1)+(u2*u2);
if (s>=1 || s<=0)
{
goto ll;
}
b = pow((-2.0*(log(s)/s)),0.5);
rmd = b*u1;
}
if (indi == 0)
{
indi=1;
}
else
{
indi=0;
}
rmd = (rmd+4)*100;
rmd = rmd/800;
diff = (rangmax-rangmin)*100;
rmd = (rmd*diff)/100+rangmin;
return rmd;
}

```

/ Functions to calculate capital, operating and dormancy costs: Follows similar algorithm to that presented in DIVERS 'X' */*

```

void calc_ccosts(void)
{
if(rand0<32767*CC1MT || COSTARRAY[pc-1][0] < COSTARRAY[0][0] * 0.05)
{
kc=0;
if(rand0<32767*CC1FT)
{
TICCCOST = sin((CC1X3*pow(XVALREF[kc][0],3)+(CC1X2*pow(XVALREF[kc][0],2))

```

```

+ (CC1X * XVALREF[kc][0]);
T1CCOST = T1CCOST + CC1TF + (CC1X2 * pow(kc, 2) + CC1X * kc) + CC1CON;
}
else
{
T1CCOST = (CC1X2 * pow(XVALREF[pc][0], 2) + CC1X * XVALREF[pc][0] + CC1CON);
}
}
else
{
if (rand0 < 32767 * CC1FT)
{
T1CCOST = ((-CC1X3 * pow(XVALREF[kc][0], 3)) + (-CC1X2 * pow(XVALREF[kc][0], 2))
+ (-CC1X * XVALREF[kc][0]));
T1CCOST = T1CCOST + CC1TF + (-CC1X2 * pow(kc, 2) + -CC1X * kc) + CC1CON;
}
else
{
T1CCOST = (-CC1X2 * pow(kc, 2) + -CC1X * kc + CC1CON);
}
}
COSTARRAY[pc][0] = T1CCOST;
kc += 1;
if (rand0 < 32767 * CC2MT || COSTARRAY[pc-1][4] < COSTARRAY[0][4] * 0.05)
{
lc = 0;
if (rand0 < 32767 * CC2FT)
{
T2CCOST = ((CC2X3 * pow(XVALREF[lc][1], 3)) + (CC2X2 * pow(XVALREF[lc][1], 2))
+ (CC2X * XVALREF[lc][1]));
T2CCOST = T2CCOST + CC2TF + (CC2X2 * pow(lc, 2) + CC2X * lc) + CC2CON;
}
else
{
T2CCOST = (CC2X2 * pow(XVALREF[pc][1], 2) + CC2X * XVALREF[pc][1] + CC2CON);
}
}
}

```



```

}
else
{
    if(rand0<32767*CC2FT)
    {
        T2CCOST = ((-CC2X3*pow(XVALREF[lc][1],3))+(-CC2X2*pow(XVALREF[lc][1],2))
        +(-CC2X*XVALREF[lc][1]));
        T2CCOST = T2CCOST+CC2TF+(-CC2X2*pow(lc,2)+-CC2X*lc)+CC2CON;
    }
    else
    {
        T2CCOST = (-CC2X2*pow(lc,2)+-CC2X*lc+CC2CON);
    }
}
COSTARRAY[pc][4] = T2CCOST;
}

void calc_ocosts(void)
{
    if(rand0<32767*OC1MT || COSTARRAY[pc-1][1] < COSTARRAY[0][1] * 0.05)
    {
        ko=0;
        if(rand0<32767*OC1FT)
        {
            T1OCOST = ((OC1X3*pow(XVALREF[ko][2],3))+OC1X2*pow(XVALREF[ko][2],2))
            +(OC1X*XVALREF[ko][2]);
            T1OCOST = T1OCOST+OC1TF+(OC1X2*pow(ko,2)+OC1X*ko)+OC1CON;
        }
        else
        {
            T1OCOST = (OC1X2*pow(XVALREF[pc][2],2)+OC1X*XVALREF[pc][2]+OC1CON);
        }
    }
    else
    {
        if(rand0<32767*OC1FT)

```

```

{
T1OCOST = ((-OC1X3*pow(XVALREF[k0][2],3))+(-OC1X2*pow(XVALREF[k0][2],2))
+(-OC1X*XVALREF[k0][2]));
T1OCOST = T1OCOST+OC1TF+(-OC1X2*pow(k0,2))+(-OC1X*k0)+OC1CON;
}
else
{
T1OCOST = (-OC1X2*pow(k0,2))+(-OC1X*k0+OC1CON);
}
}
COSTARRAY[pc][1] = T1OCOST;
ko+=1;
if(rand0<32767*OC2MT || COSTARRAY[pc-1][5] < COSTARRAY[0][5] * 0.05)
{
lo=0;
if(rand0<32767*OC2FT)
{
T2OCOST = ((OC2X3*pow(XVALREF[l0][3],3))+((OC2X2*pow(XVALREF[l0][3],2))
+(OC2X*XVALREF[l0][3]));
T2OCOST = T2OCOST+OC2TF+(OC2X2*pow(l0,2)+OC2X*lo)+OC2CON;
}
else
{
T2OCOST = (OC2X2*pow(XVALREF[pc][3],2)+OC2X*XVALREF[pc][3]+OC2CON);
}
}
else
{
if(rand0<32767*OC2FT)
{
T2OCOST = ((-OC2X3*pow(XVALREF[l0][3],3))+(-OC2X2*pow(XVALREF[l0][3],2))
+(-OC2X*XVALREF[l0][3]));
T2OCOST = T2OCOST+OC2TF+(-OC2X2*pow(l0,2))+(-OC2X*lo)+OC2CON;
}
else
{
}
}
}

```

```

T2OCOST = (-OC2X2*pow(1o,2)+-OC2X*1o+OC2CON);
}
}
COSTARRAY[pc][5] = T2OCOST;
/* Calculate cumulative costs */

if(pc == 0)
{
T1ARRAY[pc][0] = COSTARRAY[pc][0];
T1ARRAY[pc][1] = COSTARRAY[pc][1];
T2ARRAY[pc][0] = COSTARRAY[pc][4];
T2ARRAY[pc][1] = COSTARRAY[pc][5];
}
else
{
T1ARRAY[pc][0] = T1ARRAY[pc-1][0] + COSTARRAY[pc][0];
T1ARRAY[pc][1] = T1ARRAY[pc-1][1] + COSTARRAY[pc][1];
T2ARRAY[pc][0] = T2ARRAY[pc-1][4] + COSTARRAY[pc][4];
T2ARRAY[pc][1] = T2ARRAY[pc-1][5] + COSTARRAY[pc][5];
}
}

void calc_dcsts(void)
{
COSTARRAY[pc][2] = COSTARRAY[pc][1] * 0.05;
COSTARRAY[pc][6] = COSTARRAY[pc][5] * 0.05;
}

/* Function to calculate demand: Utilises similar calculation procedure to cost evaluations */

void calc_demand(void)
{
if(rand0<32767*DMT || DEMAND_ARRAY[pc-1] < DEMAND_ARRAY[0] * 0.05)
{

```

```

dc=0;
if(rand0<32767*DFT)
{
DEMAND = ((DX3*pow(XVALREF[dc][4],3))+(DX2*pow(XVALREF[dc][4],2))
+(DX*XVALREF[dc][4]));
DEMAND = DEMAND+DTF+(DX2*pow(dc,2)+DX*dc)+DCON;
}
else
{
DEMAND = (DX2*pow(XVALREF[pc][4],2)+DX*XVALREF[pc][4]+DCON);
}
else
{
if(rand0<32767*DFT)
{
DEMAND = ((-DX3*pow(XVALREF[dc][4],3))+(-DX2*pow(XVALREF[dc][4],2))
+(-DX*XVALREF[dc][4]));
DEMAND = DEMAND+DTF+(-DX2*pow(dc,2)+-DX*dc)+DCON;
}
else
{
DEMAND = (-DX2*pow(dc,2)+-DX*dc+DCON);
}
}
DEMAND_ARRAY[pc] = DEMAND;
dc+=1;
}

```

APPENDIX 2

Appendix 2 contains information relevant to the survey carried out amongst modellers and decision makers in Israel. It includes a short discussion of those issues which emerged from carrying out a survey in a language which was not the mother tongue of the main researcher. Templates for the interviews carried out and copies of the questionnaire used in both Hebrew and English are also provided.

Interview structure and approach for Israel Survey

The interviews carried out amongst senior executives in Israel were focused, where possible, on individuals who were charged with making investment decisions. Where this was an unrealistic or unachievable aim, an influential actor in the decision making process was targeted. Fourteen interviews were executed over a two month period in 1990 amongst managers in the Jerusalem, Tel Aviv and Haifa areas. The interviewees represented a variety of industrial and commercial concerns and had an average of over 15 years experience in their relative businesses. The interviews themselves were intended to achieve two goals.

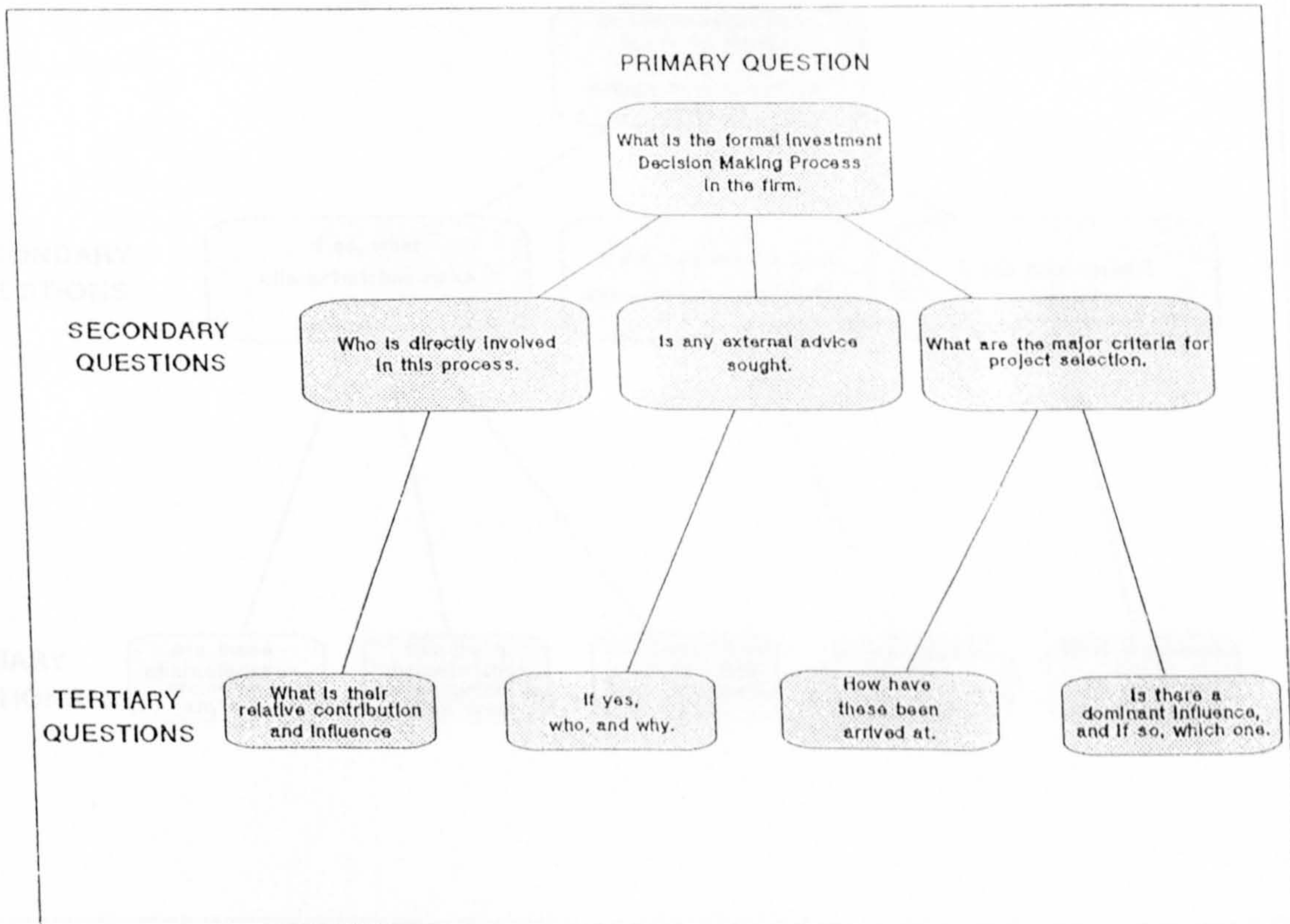
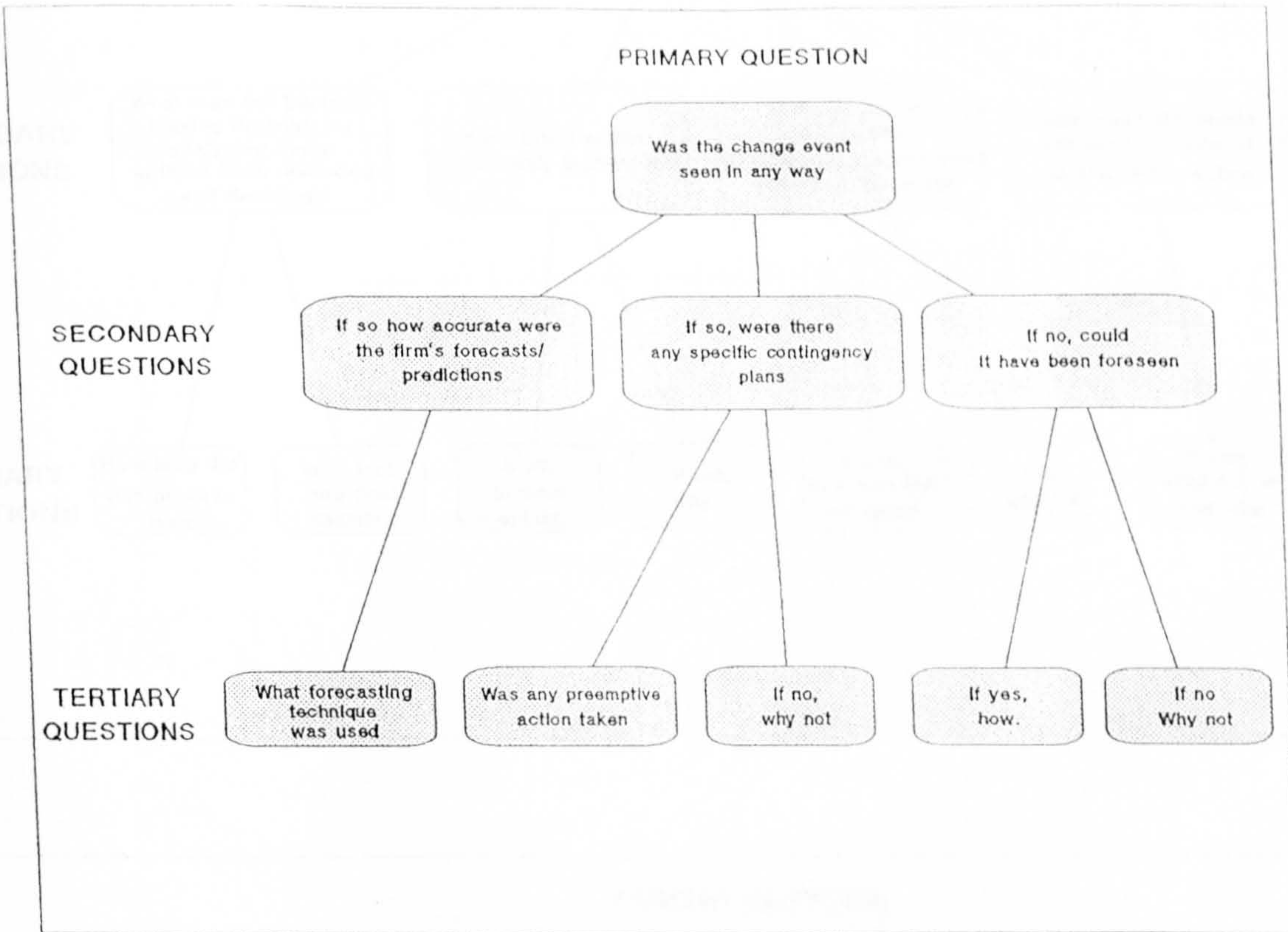
1. To provide additional questionnaire returns. (The interviewees were first talked through a copy of the mailed questionnaire).
2. To encourage the interviewee to discuss the issues of environmental volatility and flexibility / robustness within the confines of a semi-structured interview.

In order to provide a framework for the latter of these aims, an interview 'template' was developed which was intended to both bound the conversation and constitute a common frame of reference for analysis purposes. Accordingly, the interviewees were invited to consider a recent event, extraneous to their company, which had effected a high degree of surprise on management. The choice of this recent example of environmental volatility was to be influenced by the following considerations.

1. It should have been influential enough to have caused concern amongst the management team.
2. It should have taken place no more than three years ago (Thereby ensuring contemporary relevance).
3. It should be readily identifiable and lend itself to description (though not necessarily quantification).
4. There should be a specific link between the exogenous change event and the firm's operating environment.

Subsequent to the identification of a suitable event, the interviewee was guided through a 20-30 minute discussion on the themes outlined below. The template structure was characterised by a primary / secondary / tertiary query process which took key issues relating to the event and followed lines of debate through a predetermined path.

Questionnaire Templates used during survey of modellers and decision makers in Israel.



PRIMARY QUESTION

What actions were considered to deal with the influence of the event

SECONDARY QUESTIONS

What was the Decision Making Process for analysing these actions (both reviewing and deciding).

Were these actions successfully implemented

Were the actions successful in combating the unwanted effects of the event

With hindsight, would you have considered an alternative action

TERTIARY QUESTIONS

How long did this process take.

Who took the final decision

If so, to what extent.

If not, why ?

If yes, how was this achieved.

If no, why not.

If yes, what action and why

PRIMARY QUESTION

Do you consider your firm to be flexible with regard to being robust to external changes

SECONDARY QUESTIONS

If so, what characteristics make it so.

If not, how does it cope with environmental volatility

If not, how could it be made so.

TERTIARY QUESTIONS

Are these characteristics promoted in any way

Can these characteristics be recognized in other firms

How have these characteristics been developed in the firm

Do you consider your firm to be proactive or reactive

What resources would be required to achieve this

As mentioned in the main text, analysis of the interviews takes the form of a discussion of key themes, issues and comments made by individuals and the frequency with which such statements arise across the group. To aid in the sourcing of these comments, a list is presented below showing each interviewee's company sector, position, and years experience in the industry.

Interviewee No.	Industry Sector	Position	Experience
1	Chemicals	Finance Manager	12
2	Electricity Utility	Planning Manager	18
3	Electricity Utility	Finance Manager	24
4	Irrigation Equip Mnft	General Manager	18
5	Energy Resources.	Chief Executive	13
6	Oil Supply	Projects Manager	10
7	Construction	Finance Manager	22
8	Electricity Utility	Project Manager	8
9	Electricity Utility	Expansion Analyst	13
10	Electricity Utility	Project Evaluation Analyst	10
11	Pharmaceuticals	Planning Manager	28
12	Telecommunications	Planning/Eng Manager	10
13	Chemicals	Production Manager	17
14	Electronics	Finance Manager	9

Questionnaire for Survey of Israeli Management Perceptions of Uncertainty

Full copies of both the Hebrew and English versions of the questionnaire used in the survey of Israeli management attitudes to uncertainty are provided on the following pages. The design methodology is reported in detail in the main text, the opportunity is taken here to discuss some of the difficulties encountered in the design and execution of a 'bilingual' questionnaire.

The main factors which dictated the need for translation of the questionnaire and responses were;

1. To minimise non-completion because of respondents not being confident about answering a questionnaire in English.
2. To ensure that respondents were able to fully articulate their ideas and comments.
3. Researcher's own minimal grasp of Hebrew.

Formulating the language set to be used in the questionnaire raised a number of problems associated with translation and meaning. Firstly, there were not always unique synonyms for the English terms used. This is an unavoidable state of affairs which can only be addressed by rigorous and exhaustive testing of alternatives amongst a broadly based piloting group. If need be, the words and phrases under consideration should be tested in isolation, providing the opportunity for respondents to select from a range of possible alternatives. In the case reported in Chapter 7 this process took several days, but was vindicated by the low level of queries concerning this aspect of the survey.

Secondly, the industry and profession specific terminology used by respondents was, in the Hebrew, translated directly from mostly American sources. This phenomena caused problems with translation of the answers back into English, as many of the terms used were unfamiliar to the researcher, causing confusion and debate on the accuracy of the translation. In addition, there were several terms which were simply Hebraized versions of translated English phrases. These did not translate back into English as conveniently as they did into Hebrew and recourse was made on several occasions to staff at the Tel Aviv University for a complete explanation.

Finally, there were a number of terms, the precise meaning of which were culturally specific. For instance, concepts of time and value had to be confirmed with regard to relative magnitudes. A further example of this problem concerned the benefit criteria used for project selection and technology investment. These were influenced by a broad range of issues, many of which were incongruent with those found under the free market economies of Western Europe.

The above outlined problems were all identified during the survey activity and required careful attention to the minutiae of questionnaire design and analysis. The major lesson to be learned is that differences in language result in changed perspectives. This has an effect on both the relationships between concepts and the assessment and measurement of phenomena. Language provides effective bounds on our ability to communicate our ideas, thoughts and beliefs; providing perhaps the closest measure of paradigm available to outsiders.

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Cranfield

August 1990

Dear Sir / Madame,

This letter serves to both introduce myself, and to request your assistance in completing the enclosed questionnaire.

I am currently visiting Israel as part of my doctoral research programme with the Innovation & Technology Assessment Unit at the Cranfield Institute of Technology (one of the U.K's leading postgraduate institutions). My studies in Israel are also supported by the Anglo-Israel Association, who have kindly provided a scholarship award to help fund my work.

The research area is centred around the use of investment appraisal techniques by industrial concerns with particular emphasis upon the ways in which uncertainty and change are managed by individual companies. By conducting part of the research in Israel it is hoped that specific links between investment appraisal techniques, the political/economic environment, and long term strategic planning can be identified. Overall, the research project aims to obtain an understanding of investment appraisal under different conditions and will move towards developing a more robust and flexible strategy to aid the decision maker in assessing capital investment projects. Therefore, involvement in the survey will have an indirect but specific long term benefit to your company.

Accordingly, your assistance in completing the attached questionnaire would be much appreciated. The questionnaire is presented in Hebrew and should be completed by the date shown on the cover page. Those companies which return a set of completed questionnaires will be sent a report reviewing the survey's main findings.

Any information provided by your company would be treated in the strictest confidence and would only be used within the framework of the study as a whole. No specifically attributable information will be published, the results of the survey only being released in non-company specific statistical data. I hope that you will consider it beneficial to participate in the survey and I thank you in advance for your co-operation.

Yours Sincerely,

Paul Jeffrey (Bsc. Msc.)

IMPORTANT: PLEASE READ THESE INSTRUCTIONS BEFORE COMPLETING THE QUESTIONNAIRE:

The purpose of this questionnaire is to enquire into perceptions of volatility and uncertainty within Israeli industry and to identify those policies and techniques which are used in order to combat such uncertainty.

Some of the following questions involve the use of terms and phrases, the understanding of which is important for the accuracy of the study. Accordingly, these questions are prefaced by a short explanation of the terms involved.

Please be wary and differentiate between those questions which relate to your own personal views / experience, and those which pertain to the company's activities and which expressly identify 'the company' or 'the firm'.

Please attempt to answer all questions. It would also be of help if you could make a distinction between those questions which you feel are not applicable (answer N / A), and those which you feel unable to answer due to incomplete information. In the latter case please enter 'don't know'.

May I take this opportunity to thank you for your interest in the study and I hope that answering the questions will prove a useful exercise to you in itself. Once again I would stress that any information you provide will be treated in the strictest confidence.

Q1. Name of person completing the questionnaire

Q2 Job title

Q3. Please provide a brief summary of your responsibilities and function within the firm.

Q4. How long have you held your current position with the company ?

Q5. Please provide a brief outline of your previous working experience and qualifications.

NOTE: The following question includes the term 'business environment'. In the context of the questionnaire this term relates to the state of the economic, social, political, and technological world within which your company operates.

Q6. When you think about your company's business environment, what are the four or five most important influences that come to mind ?

1.
2.
3.
4.
5.

NOTE: The next question includes the terms 'volatility' and 'impact'. In this questionnaire the term 'volatility' relates to the magnitude or frequency of changes of state. i.e. how often or by how much the influences itemised by you in answer to Q6 changed. The term 'impact' refers to the effect which the influence had upon your company's ability to operate effectively and efficiently.

Q7. How would you characterise the volatility and impact of each of the influences itemized by you in answer to Q6 as having been over the past 5 years. Please circle as appropriate.

Influence No.	Frequency of change			Magnitude of change			Impact of change		
	Low	Med	High	Low	Med	High	Low	Med	High
1	Low	Med	High	Low	Med	High	Low	Med	High
2	Low	Med	High	Low	Med	High	Low	Med	High
3	Low	Med	High	Low	Med	High	Low	Med	High
4	Low	Med	High	Low	Med	High	Low	Med	High
5	Low	Med	High	Low	Med	High	Low	Med	High

Q8. What impact do you expect the influences itemized by you in answer to Q6 to have on your firm's activities over the next 5, 10 and 15 years. Please mark 'H' for high, 'M' for medium, and 'L' for low.

Influence No.	0 - 5 years	0 - 10 years	0 - 15 years
1			
2			
3			
4			
5			

Q9. Is any attempt made within the company to monitor or forecast specific variables associated with those influences identified by you in answer to Q6 ? If so, please list and indicate which are monitored and / or forecast.

VARIABLE	MONITORED	FORECAST
1		
2		
3		
4		
5		
6		

Q9a. Please indicate how those variables listed in answer to Q9 (above) are monitored or forecast.

- 1.
- 2.
- 3.
- 4.
- 5.

Q10. Are there any policies / techniques which you use in your work in order to explicitly combat the uncertainty of your company's business environment ? If so, please list.

- 1.
- 2.
- 3.
- 4.
- 5.
- 6.

Q11. What additional policies / techniques are you aware of which can be utilized to combat the uncertain aspects of your firm's business environment. (That is in addition to those utilised by yourself and listed in answer to Q10).

- 1.
- 2.
- 3.
- 4.

NOTE: The following question includes the term 'investment plans'. In the context of this questionnaire, 'investment plans' relates to the formal preparation of projects which involve the use of capital resources (in the form of money, manpower or machinery) in order to further the company's aims.

Q12 Are you, as part of your job, involved in the preparation, or assessment, of investment plans ? If so, what type of investment planning are you involved in and what role do you play ?

TYPE OF INVESTMENT	ROLE
1.	
2.	
3.	
4.	

Q13. When considering investment plans as part of your job, do you utilise any formal investment analysis techniques ? If so, please list those techniques used.

1.
2.
3.
4.
5.
6.

Q14. Do the investment analysis techniques itemised by you in answer to Q13 (above) involve an assessment of risk / uncertainty. If so, how is risk / uncertainty included in the analysis.

--

Q15. Are discounting techniques used in the investment analyses which you are involved in ? If so, please indicate what types of analyses include its use and indicate what Discount Rate or equivalent (i.e. Internal rate of return etc.) is / has been used.

TYPE OF ANALYSIS	DISCOUNT RATE USED(%)			
	TODAY	5YRS AGO	10YRS AGO	15YRS AGO
1				
2				
3				
4				
5				

Q16. Please give details of how the discount rate currently used by your company is selected.

Q17. When thinking about plans of any nature which the company has made but which have not been implemented correctly, what are the five or six main reasons which come to mind ?

- 1.
- 2.
- 3.
- 4.
- 5.
- 6.

Many thanks once again for taking an interest in this study.

**I hope that you have found answering the questions of
interest.**

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אדון/גברת נכבד/ה,

במכתב זה ברצוני להציג את עצמי ולבקש את שיתוף הפעולה שלכם במילוי השאלון המצורף.
בימים אלה אני מבקר בישראל לצורך הכנת עבודת הדוקטורט שלי הנועשית במסגרת היחידה להערכה וחידוש טכנולוגי (Cranfield Institute of Technology), אחד ממוסדות ההשכלה הגבוהה המובילים בבריטניה. עבודת המחקר שלי ממומנת בחלקה גם על ידי התאחדות האנגלו-ישראלית שהעניקה לי בטובה מילגה כדי לסייע במימון המחקר.

הנושא שבו מתמקד המחקר הוא: השימוש שעושים מפעלים תעשייתיים בכלים להערכת השקעות עם דגש מיוחד על הדרכים באמצעותם מתמודדות חברות שונות עם חוסר וודאות ושינוי.
עריכת חלק מן המחקר בישראל תאפשר, אולי, לזהות קשרים ספציפיים בין הכלים (הטכניקות) להערכת השקעות והסביבה הכלכלית פוליטית, ותכנון אסטרטגי לטווח ארוך.

באופן כללי המחקר נועד להשגת הבנה של הערכת השקעה בתנאים שונים ויתקדם לקראת פיתוח אסטרטגיה גמישה יותר שתסייע למקבלי ההחלטות בהערכת תכניות השקעה. לפיכך למעורבותכם בסקר תהיה תועלת עקיפה אך ארוכת טווח וספציפית.

עזרתך במילוי השאלון המצורף תתקבל בהערכה רבה. השאלון כתוב עברית ויש לסיים ולמלא אותו לא יאוחר מהתאריך הרשום בשאר השאלון. לחברות ששייבו את השאלונים המלאים ישלח דו"ח המסכם את הממצאים העיקריים של הסקר.
למותר לציין שהמידע שיסופק לנו על ידך יטופל ביסודיות מירבית, לא יפורסם שום מידע מיוחד באופן ספציפי, שכן תוצאות המחקר יפורסמו רק כמידע סטטיסטי בלתי תלוי.

אני מקווה שתפיקו תועלת מההשתתפות בסקר ואני מודה לכם מראש על שיתוף הפעולה.

בכבוד רב,

פול ג'פרי (Bsc. Msc.)
Paul Jeffrey (Bsc. Msc.)

**TEXT BOUND INTO
THE SPINE**

חשוב: אנא קראו את ההוראות לפני מילוי השאלון

בכוונת שאלון זה לבדוק כיצד נתפסת הפכפכות ואי-ודאות בתעשייה הישראלית ולזהות את המדיניות והטכניקות בן נוקטים כדי להאבק באי-ודאות זו. מידת הדיוק של הסקר תלויה בהבנה נכונה של ביטויים ומושגים שיופיעו בן השאלות. לכן אקדים לשאלות אלה הסבר של המושגים או הביטויים שיופיעו בהן. אנא שיח/י לב והבחינ/י בין השאלות המבקשות את דעתך האישית בנושא מסוים והנסמכות על נסיונך האישי ובין השאלות הקשורות לפעילויות החברה. באחריות יופיעו הביטויים "החברה" או "המפעל".

אודה לך באם תוכל/י להבחין גם בין שאלות שאינן ישימות (רשמ/י ל.י.) ושאלות שאינך יכול/ה לענות עליהן מסיבות של חוסר מידע (רשמ/י לא יודע/ת) אנא נסו לענות על כל השאלות.

ברצונ/י לנצל הזדמנות זו כדי להודות לך על העניין שהראית בסקר ואני שמילוי השאלון יהווה התנסות מעניינת כשלעצמה. ושוב ברצונ/י להדגיש מידע שחספק/י לנו יטופל בסודיות מוחלטת.

1. שם האדם הממלא את השאלון.

2. הגדרת התפקיד.

3. נא ציינ/י בקצרה מהם התחומים עליהם את/ה מפקד/ת בחברה.

4. כמה זמן את/ה נושא/את בתפקיד הנוכחי?

5. נא ציינ/י בקצרה נסיון/תפקידים קודמים וכן השכלה וכישורים נוספים.

הערה:

בשאלות הבאות יופיע המונח "סביבה עסקית". בהקשר הנוכחי המונח מתייחס למצב הכלכלי, הסוציאלי, הפוליטי והטכנולוגי אשר בו פועלת החברה.

6. בחושבך על "הסביבה העסקית" בה פועלת החברה שלך מהן ההשפעות העיקריות עליה הצצות במוחק ציינ/י 4-5.

הערה:

בשאלה הבאה מופיעות המילים "הפכפכות" ו"אימפקט" (impact - השלכה) בהקשר הנוכחי המונח הפכפכות מתייחס לגודל או תדירות השינוי במצב (לדוגמא, באיזו תדירות או גודל עשויות ההשפעות העיקריות שציינת לעיל להשתנות). המונח אימפקט מתייחס לאפקט שיש להשפעות על יכולת החברה לתפקד ביעילות ובאפקטיביות.

7. איך תאפיין/י את ההפכפכות והאימפקט של כל אחת מההשפעות העיקריות שציינת בשאלה הקודמת (6) במשך חמש השנים האחרונות. נא לסמן בעיגול את התשובה המתאימה.

גורם משפיע	אימפקט השינוי	גודל השינוי	תדירות השינוי
1	וגבוה בינוני נמוך	וגבוה בינוני נמוך	וגבוה בינוני נמוך
2	" " " "	" " " "	" " " "
3	" " " "	" " " "	" " " "

8. איזה אימפקט אתה מצפה שיהיה להשפעות שציינת בשאלה Q6 על פעילות שלך ב 5, 10, ו- 15 השנים הבאות.

ציין/י נ. לנמוך. ב. לבינוני. ג. לגבוה.

גורם משפיע	0 - 5 שנים	5 - 10 שנים	10-15 שנים
1			
2			
3			

9. האם נעשה ניסיון כלשהו בחברתך לחזות משתנים ספציפיים הקשורים להשפעות העיקריות שציינת בשאלה (6) או לעקוב אחריהם? אם כן נא רשום/י את המשתנים וציין/י ב- אם נחזו או נעקבו.

נחזה נעקב משתנה ספציפי

9א. נא ציין/י כיצד נערך החיזוי או המעקב על המשתנים שרשמת בתשובה לשאלה הקודמת.

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10. האם יש מדיניות או טכניקות בהם אתה/ה נוקט/ת בעבודתך כדי להאבד באי-הודאות של הסביבה העסקית בה פועלת החברה שלך? אם כן ציין/י מהם.

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11. האם יש עוד טכניקות בהן אפשר להעזר, או מדיניות נוספת שאפשר לנקוט כדי להאבק בתנאים של אי-ודאות בסביבה העסקית של חברתך? זאת בנוסף לאלה שאת/ה כבר נוקט/ת ושרשמת לעיל.

הערה:

בשאלה הבאה יופיע המונח "תכניות השקעה". בהקשר הנוכחי ו"תוכניות השקעה" מתייחס לתכנון רשמי של פרויקטים כאשר הפרויקטים כוללים שימושים במשאבי הון בצורת כסף, כח אדם, ומיכון. כל זאת כדי לקדם את מטרות החברה.

12. האם את/ה במסגרת תפקידך מעורב/ת בהכנה או הערכה של תוכניות השקעה? אם כן באיזה סוג של תוכניות השקעה את/ה מעורב/ת ומהו סוג המעורבות שלך?

סוג ההשקעה

סוג המעורבות

13. בהנחה שתוכניות ההשקעה הן חלק מעבודתך האם את/ה עושה שימוש בטכניקות פורמליות (ידועות) לניתוח השקעות? אם כן נא רשום/י טכניקות אלה.

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14. האם הטכניקות הפורמליות לניתוח השקעות שרשמת לעיל בשאלה 13 לוקחות בחשבון הערכה של סיכונים ואי-ודאות? אם כן כיצד הסיכונים/אי-הודאות נכללים בניתוח ההשקעות?

15. האם נעשה שימוש בטכניקות היוון במסגרת ניתוח ההשקעות בהן את/ה מעורב/ת? אם כן נא ציין/י אילו סוגים של ניתוחי השקעות כוללים שימוש בהיוון ובאיזה שיעור היוון או שיעור מקביל (למשל שער מדד פנימי וכד').

16. נא פרט/י כיצד נבחר שיעור ההיוון שבו משתמשים כיום בחברתך

17. חשב/י על תוכניות מסוג כלשהו שחברתך ערכה ואשר לא יושמו. אילו חמש/שש סיבות לכך עולות בדעתך?

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ושוב רוב תודות על התעניינותך בסקר. אני תקווה שמצאת עניין במילוי השאלון.

APPENDIX 3

The information in this appendix relates to the survey reported in Chapters 6 and 7 amongst Operational Research practitioners who are members of the OR Society. The following pages present a short summary of the background to the collaboration with the OR society. This is succeeded by a copy of the questionnaire as it was sent to potential respondents.

Support from the Operational Research Society

Approaching professional personnel within an official organisational setting can often be a difficult and frustrating task, particularly when there is a need to induce some response from the targeted population. Problems associated with this mode of investigation include a lack of perceived credibility by potential respondents towards the investigator, and deficiencies in the level of appreciation for the problems being addressed. Such difficulties can lead to major complications when the response sets are being interpreted and analysed. One procedure which can reduce the possibility of negative attitudes being adopted by respondents in these situations involves advancing the study as part of a broader programme supported by a relevant professional institution or association. Gaining the endorsement of such bodies, and if possible their assistance or co-operation, provides a positive image to project to the response group. It also ensures at least a minimum level of authority and prestige for the work, thereby enhancing its perceived worth or value.

As an appropriate vehicle for supporting the modeller's questionnaire, the Operational Research Society (UK), were contacted through their general manager to ascertain the possibility for co-operation. After consultations with the Society's president, who expressed an interest in the research and gave preliminary approval for the proposed collaboration, a meeting was held at their national offices in Birmingham where the questionnaire format was discussed and negotiations took place regarding the issue of access to the society's membership list. It was agreed that the Society would provide a subset of this list from the membership data base using a search criteria relating to the industry association of each entry. It was also arranged for the Society's general manager to sign a covering letter to be included with the questionnaire which provided an introduction to the work and invited participation in the questionnaire study. Questionnaire design was not influenced by the Society although copies of early draft and final versions were submitted to the Birmingham office prior to distribution.

Whilst there is no evidence to suggest how successful the questionnaire would have been without the support of the OR society, there is little doubt that the overall satisfactory quality and quantity of responses achieved would have been much diminished in the absence of the Society's endorsement.

**Innovation & Technology Assessment Unit
International Ecotechnology Research Centre
Cranfield Institute of Technology. Cranfield. Beds. MK43 0AL**

Research Programme:

*'The conceptualization and representation of
risk, uncertainty, and surprise in decision support processes:
A multidisciplinary approach to technology selection.'*

Researcher: Paul Jeffrey

Draft proposal for a collaborative research activity
with the Operational Research Society.
June 1992

Background

This research programme, now in its third year, has focused on the phenomena of risk and uncertainty, and their influence on the planning function. Two strands of research have been followed; a behavioural strand which investigated both attitudes to risk and uncertainty under specific conditions and the use of formal modelling techniques within organizations, and a methodological strand which focused on the representation of risk, uncertainty and surprise within models which seek to support decision making in technology choice situations.

The behavioural study exposed the following phenomena:

- Key determinants of attitudes to risk and uncertainty may be socio-cultural in nature and difficult to replicate.
- In environments which are characterised by turbulence in the magnitude of key operating variables, management seeks to adopt policies which are selected by consensus, are widely considered to be achievable, and which exhibit flexibility.
- In addition, these organizations display high degrees of adaptability with regard to individual's roles, organizational aims, and management / operational structure.

- The use of formal modelling techniques is often circumvented by decision makers who apply an alternative criteria set for the selection of formal investment projects.

The methodological work has highlighted some of the practical limits to modelling techno-economic phenomena pertaining to technology selection. It has also identified specific characteristics of both the technologies themselves and their operating environments, which influence the relative success of different planning strategies and, through these, different modelling approaches. In particular, a reassessment of the phenomena of risk, uncertainty and surprise promotes the use of adaptability as one element of a robust strategy.

In addition to the above, one very specific issue has emerged regarding the use of explicit approaches to dealing with risk and uncertainty in formal analysis / modelling procedures. Evidence from the earlier work suggests that there may be incongruence of understanding about risk, uncertainty and surprise at different levels of the organization. In particular the following phenomena are indicated:

- The terminology lacks a common interpretation.
- The subtleties and complexities of the studies carried out by O.R. and planning practitioners are lost during communication to decision makers.
- A lack of congruence exists between modellers and decision makers with regard to selection criteria and relevant parameter definition

These issues form the central concern of the proposed research activity. The structure of the problem set suggests that any investigative process should be focused on two target groups. The first of these will comprise middle managers of medium - large engineering concerns who are involved in the use of models and modelling techniques as input to decision making processes. The second group will consist of senior (preferably board level) managers who are responsible for decision making on issues of technology selection in similar types of firm. It is the first of these groups which is the focus of this proposal.

Research Activity:

In more detail the research will be concerned with eliciting information to contribute to a discussion of several propositions including:

- 1) The determinants of the use of specific models and methodologies, and the strength of the link between model output and decision is strongly influenced by a specific view as to the nature of risk, uncertainty and surprise. In particular an acceptance of the difference between subjective

uncertainty about the future magnitude or state of a particular variable and the actual magnitude or state as the future unfolds is crucial to a reassessment of planning methodologies and strategic tools.

- 2) Attitudes to risk, uncertainty and surprise will be reflected in strategic policy formulation.
- 3) Successful strategic approaches to combating risk, uncertainty and surprise reflect an appreciation of: a) the difference outlined in 1 (above), and b) the key elements identified in the methodological strand of the research (technology scale, lifecycle etc). Furthermore, such strategies will exhibit both optimizing and adaptive characteristics in the planning and control functions.

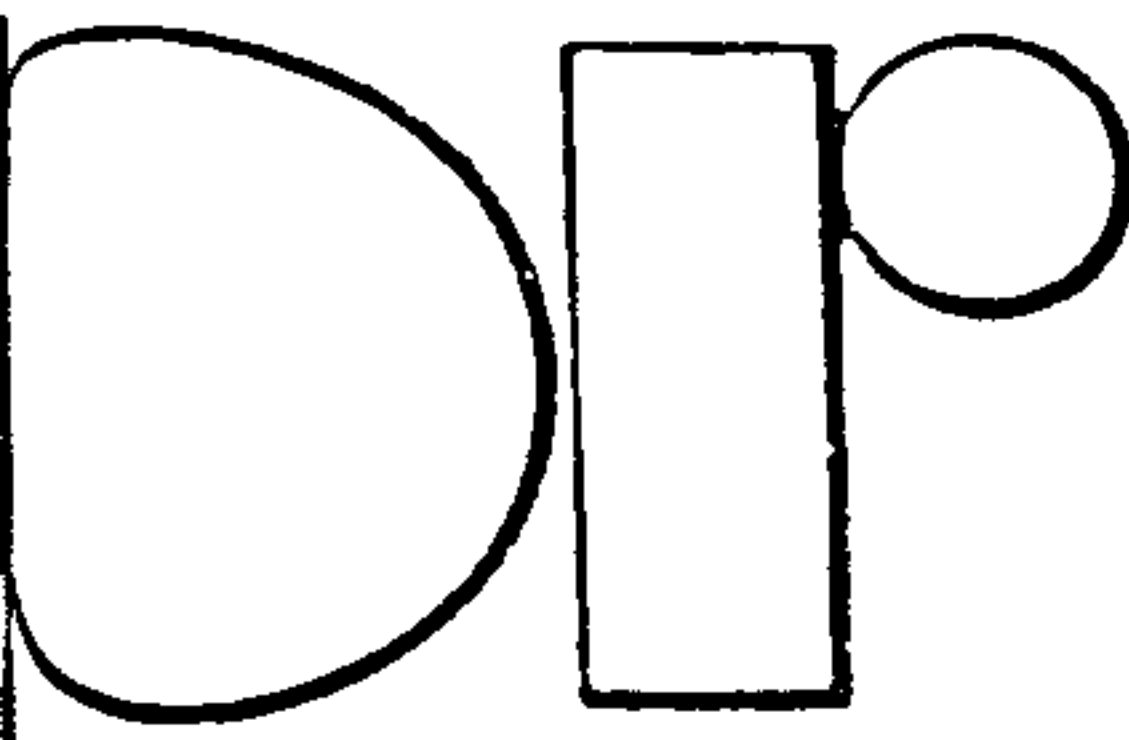
With regard to data collection techniques, carefully formulated questionnaires and structured interviews have both been utilised during this research programme. In the present case however it is felt that the nature of the information required is such that a questionnaire format is most suitable. The target group would consist of O.R. practitioners currently employed by industrial / utility concerns which, as part of their operations, engage in technology selection decision making processes.

Collaboration.

In order to gain the co-operation of a suitable respondent group, the support of the Operational Research Society is being sought. Specifically this would involve providing access to membership details so that relevant individuals can be identified and the questionnaires satisfactorily targeted. In addition, the motivation to respond to the questionnaire would be greatly enhanced if the Society were to lend its 'name' to the study. This could take the form of a covering letter supporting the work.

In recognition of this support, a paper would be prepared by the researcher responsible for carrying out the survey, and submitted to the Society as a report on this particular activity & its findings. As this is an ongoing research topic, it is hoped that the proposed collaborative study could form the basis for additional activities of mutual interest and benefit.

All information provided by respondents would be treated in the strictest confidence and all reported results would not be respondent specific in form.



OPERATIONAL
RESEARCH
SOCIETY

NEVILLE HOUSE, WATERLOO STREET,
BIRMINGHAM B2 5TX
Telephone No.: 021-643 0236
Fax No.: 021-631 3485

July, 1992

Dear

As an Operational Research practitioner you are uniquely placed to provide insights into the role which O.R. performs in the development of industrial and commercial business strategies. Such insights play an influential role in policy analysis and can act to both clarify current decision making processes and facilitate the development of new business strategies.

The attached questionnaire is part of an ongoing study being carried out by the Innovation and Technology Assessment Unit at the Cranfield Institute of Technology, and this particular element of the work is supported by the ORS. A small sub-group of ORS members have been selected for inclusion in this survey and we hope that you can find the time to participate in what is an interesting piece of research. The results of the study will be reported in one of the Society's publications.

Many thanks in advance for your co-operation.

Yours sincerely,

Dr. J.F. Miles
Secretary & General Manager

**INNOVATION & TECHNOLOGY ASSESSMENT UNIT,
CRANFIELD INSTITUTE OF TECHNOLOGY
TOGETHER WITH THE OPERATIONAL RESEARCH SOCIETY**

Practitioner Survey of ORS Members

July 1992

Thank you for showing an interest in this survey and taking some time to complete the attached questionnaire. Please read the following points of information before starting. Filling out the questionnaire should take about 15-20 minutes and we hope that you find the experience both thought provoking and rewarding.

**Paul Jeffrey
Programme Coordinator
INTA/IERC
Cranfield Institute of Technology
Cranfield.
Beds. MK43 0AL**

- * Please try to complete the questionnaire in an uninterrupted period of time.
- * Try to answer the questions as fully as possible. An extra sheet of paper is provided at the back for continuation of answers & any other comments you may have.
- * Please return the completed questionnaire in the prepaid envelope provided.

All information recorded will be treated in confidence and will not be used other than for the purposes of this study.

The focus of interest for this questionnaire is the assessment of long term capital equipment investment projects. It would assist the analysis of your responses if you would confine your comments to this type of activity.

Question 1.

Please state how many years experience you have in the use of O.R. techniques in a commercial / industrial setting.

Question 2.

*Which of the following methods and techniques have you practical experience of ?
(Please tick)*

Cost Benefit Analysis

Cognitive Mapping

Conflict Analysis

CPM

Decision Support Systems

Delphi Processes

Dynamic Programming

Expert Systems

Forecasting (Please state types of variable forecast)

Fuzzy Sets

Goal Programming

Integer Programming

Least Cost Planning

Linear Programming

Markov Processes

PERT

Project Management

Quadratic Programming

Queueing Theory

Risk Analysis

Stochastic Programming

Others (Please state.)

Please base your responses to questions 3 - 10 on a current or recent project which you are/have been involved with.

Question 3

Please provide a brief description of the project under consideration.

Question 4.

What particular analysis techniques were used during the assessment of this project ?

Question 5

Why were these techniques utilised rather than possible alternatives ?

Question 6.

What reservations do you have about using these particular techniques for this project ?

Question 7.

Please identify four or five major sources of doubt associated with the project.

- 1.
- 2.
- 3.
- 4.
- 5.

Question 8.

How were each of these sources of doubt treated during the analysis ?

- 1.
- 2.
- 3.
- 4.
- 5.

Question 9

What were the anticipated internal and external causes of variance between the performance of your model and the operationalization of the investment plan ?

Internal

- 1.
- 2.
- 3.
- 4.

External

- 1.
- 2.
- 3.
- 4.

Question 10

When reporting on the O.R. analyses as part of the decision making process, how, if at all, were the concerns mentioned in answer to Question 9 addressed

Internal

- 1.
- 2.
- 3.
- 4.

External

- 1.
- 2.
- 3.
- 4.

Please complete the following statements.

Statement 1

The advantages to the organization from employing Operations Research techniques are...

1.
2.
3.

Statement 2

The dangers to the organization from employing Operations Research techniques are...

1.
2.
3.

Many thanks for your time and cooperation in completing this questionnaire.

Please return the completed form in the envelope provided.

This space is provided for extended answers and for any general comments you may have concerning the use of O.R. techniques.