SYSTEMS THINKING IN TECHNICAL CHANGE:

AN ANALOGICAL MODELLING APPROACH

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Thesis Submitted for the Degree of Doctor of Philosophy

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LONDON

NOVEMBER 1990

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ACKNOWLEDGEMENTS

The author wishes to express special thanks to his supervisor, Mr. Keith Ellis, for his comments, contribution through discussion, and on reading the manuscript. Thanks are also due to Mr. David Watson, and Mr. Bruce Armstrong for creating the conditions necessary for a successful period of field research at the I.C.L Manufacturing and Logistics site, Kidsgrove. Finally, I would like to acknowledge the general support given to me by the Department of Systems Science, City University.

DECLARATION

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ABSTRACT

This research argues that the subject of technical change has, rather surprisingly, continued to utilise old-fashioned ideas to illustrate its causes and effects. A review of technical change models indicates a continuing reliance on the production function and equilibrium structures to explain various aspects of technical change. The need to determine a new comprehensive interpretation for the structure of technical change is advocated by using a systems based investigation. This is examined by illustrating the utility of Stafford Beer's (1984) methodology of topological maps in developing a system scientific model of technical change. The methodological application of the adaptive whole system and viable system in the analogical context to technical change, presents a basis for developing the systems model. This provides a unique approach which produces a systems modelling reinterpretation for the structure and functions of technical change. An evaluatory analysis of the model, using both theoretical evidence and practical field research in a U.K based microelectronics company, finds that a basic structural complementarity exists between known characteristics of technical change and the viable systems model. In addition, it is also shown that this new structural and functional model provides an alternative direction for illustrating the necessary managerial control preparations for viable technical changes, and an explanation of its causes and effects. Based on these findings, recommendations are made for continued systems research in technical change.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Research Project

In 1983, Duncan Ironmonger identified that an 'economic need' existed for technical development. The economic advantage which could be gained by effectively describing a process of technical change would result from the production of effective technical systems which would maintain economic stability and growth, whilst reducing the general tendency of technical changes to produce frequent economic instabilities. Ironmonger's (1983) conclusions were that a growing movement towards economic instability was developing through the increased rate of technical changes, and could be identified as a direct consequence of the continued application of outmoded ideas for coping with technical developments. These ideas illustrated the use of inappropriate positive feedbacks, which increased the prospect of instability. There was then a real need to discover and adopt new ideas which would provide a specific controlling influence on the process of technical change. If such ideas were to be sought, they had to be derived from the use of appropriate characteristics identified within the current process of technical change, and organised in such a way as to provide the necessary combinations of positive and negative feedback structures.

It is comments such as these which have provided the catalytic activity for this systems based research concerning the type of structures and dynamic forces operating in the process of technical changes. The most influential work in this area had appeared over forty years ago. In 1939, Schumpeter (1939) had attempted to identify a possible relationship between the economic dynamism of technical innovation which could also be coupled with the equilibrating forces of business cycles. It is through this pioneering work that a probable link between the dynamics of economic growth (and assumed technical development) and that of a general equilibrium theory was defined. But in many respects, and according to Freeman (1988) either, the formalisation of this work, or an substantial extension to it, has never been made. Subsequently, questions concerning the coherence and consequences of Schumpeter's (1939) propositions involved in contemporary technical changes, illustrate the limited impact such an analysis has had on explaining the specific structure and behaviours associated with the introduction of new technologies.

Schumpeter's (1939) work which had identified the relationship between the dynamic and equilibrating mechanisms involved in technical developments had been prompted by practical necessity, at a time when the 'Fordist' paradigm of technical development was just emerging. Where technical changes were principally derived from new methods of production in the car industry, and the electro-technical industry. These were evolving such that, mass production techniques and Taylorist labour organisation were the general consequences to the introduction of these new technologies (Roobeek, 1987).

But the dynamism associated with the development of the Fordist paradigm which was generally related to the accumulation of car, petroleum, chemical and electronic technologies, also provided new areas of technical instabilities and introduced problems of controlling the impacts of these innovative technologies. A number of factors identified by Roobeek (1987) affected the continual technical growth in the Fordist technical style. These introduced some destabilising effects in these industrial sectors. these included:

(i) a declining productivity growth (explained by the maturity phase of most process technologies) and an inability to find new mass markets led to a technical rationalisation and a stagnation in economic growth and hence, an under utilisation of technical capacity.

(ii) A decline in productivity coupled with a rise in wages was interpreted as a second destabilising factor which led to the stagnation of further technical improvements.

(iii) A limit in market expansion, which was generated through rapid saturation of international markets. In the developing countries market expansions were limited by political and financial pressures. This led to further technical stagnation and instability.

(iv) The continuing rise in new technical introductions led to a serious over capacity of technologies caused at a time when technical demand was falling. The effect was the realisation that technical investment was generally non-productive, and although this was partly a consequence of the type of technology which was used, the impact was that the development of technical improvements were seen as an economically uncertain activity.

(v) Technical developments were not paralleled with quality improvements. This resulted in production of new technologies which consisted of low reliability and hence, economic uncertainty.

The upsurge of these destabilising forces created the introduction of new technologies which attempted to avoid these fundamental instabilities within the industrial sectors. For Roobeek (1987), the three main technologies of microelectronics, biotechnology and new materials appeared to offer some solutions to the existing control problems. These technical developments provided an opportunity for new technical characteristics of miniturisation and dematerialisation. Examples of these new technical advances were identified as: (i) flexible automation, (ii) information technology, (iii) computer integrated manufacture, (iv) high value added crops, (v) independent climatic factories, (vi) advanced ceramics, (vii) renewable materials, and (viii) lightweight materials. They were seen as new technologies which could not be affected by the instabilities of the Fordist paradigm But even though these technical advances offered new routes towards economic growth and stability, Chacko (1975) maintains that they currently present a new set of problems associated with instability and control, not just in terms of economics but also in new areas of political, social and human relations.

In the face of the enormous increase in technical complexities, the basic issues concerning the dynamics and structure of technical changes still dominate. In addition, the accumulation of knowledge currently spans a wide range of disciplines, from economic and political, to manpower and skills planning (West, 1972). As a result, there is now an urgent need to identify the structures, characteristics and relationships held within the process of technical changes which involve the dynamism of new technical developments with the production of technical instabilities which frequently create a temporary state of technical stagnation.

If only to prevent instability growing into general uncontrollable social and economic chaos, a new form of control for technical change is required. For Roobeek (1987), this blueprint for a new concept of control still has to be determined. The present direction of technical change research adequately illustrates an understanding of the increase in technical complexities and associated characteristics, but not the means to control those forces. The systems research addressed in this dissertation is used to derive a structure in which these key areas of dynamic and unstable technical activities are examined, and not to promote them simply as a consequence to the dramatic growth in post-Fordist technical improvements which have brought remarkable changes to industrial practice. This explosion in new technology developments has been to stimulate the systems research to form basic diagnostic, and preparative associations which are concerned with the structure of technical changes and the potential instabilities of the firm.

The possibility of technical instabilities, as derived from information technology, microelectronics and new material technology, lie in many areas. Sahal (1979b) published an article aimed at presenting a theory of evolution for technical systems. It suggested that short term stability was actually governed by the dynamics of a particular technology, whereas long term instability tended to be governed by the dynamics of the economic system which contained the technology. Further, MacDonald, Lamberton and Mandeville. (1983) indicated that the growing tendency of economic contributions to technical change sought a means to understand the ways in which technology was created and conditioned by the functioning of the economic system, and yet was also capable of providing instabilities for that same system. Indeed in her concluding remarks, Annemieke Roobeek (Roobeek, 1987) identified a possible direct link between the hidden dynamism associated with the increased promotion and application of new technologies, with the stability or control problems of maintaining a particular 'style' (Perez, 1983) of technology. Yet according to Freeman (1988, p. 6) a purposeful economic investigation into the relationship between dynamical forces and the equilibrating mechanisms of technical developments "... is still largely unfulfilled."

Other areas of instability are not simply confined to economic descriptions of technical change. The Fordist paradigm of technical developments brought with it new forms of social practices at work. The Taylorist labour organisation had been developed in order to bring new forms of control to labour instabilities produced from the introduction of new mass production techniques. Similar instabilities emerged in the first automation debate of the 1950's and 60's where social instabilities were identified as a direct consequence to the development of new technologies (Benson and Lloyd, 1983, p. 73). In general these instabilities of the Fordist technical paradigm emerged in terms of: (i) levels of grievance, (ii) the form of management control, (iii) degrees of labour involvement and (iv) alienation (Rose, 1978, pp. 175-223).

With the rise of the post-Fordist era of technical development, these instabilities in the content of work and the relationship between management and employees also changed. The requirement was that new forms of control were needed in the area of human resource. Essentially instabilities in human resources have been identified by: (i) changes in work ethics, (ii) 'footloose' labour, (iii) fewer workers, (iv) training, (v) skill requirements and (vi) a change in lifestyles to the new technologies. But in terms of controlling these technically derived problems, only a few theorists have attempted to tackle this problem of control. Indeed, Utterback and Abernathy (1975) simply suggest that process technologies require a minimal level of consistency in order for new technologies to emerge. Yet the same consistency over a longer time period acts so as to restrict social capacities for further technical changes. In 1985 Godet's hypothesis indicated that technical options should be submitted to a closer level of social control. In another example, Blackler and Brown (1986) illustrate that there is a need to introduce intervention techniques which could expose the indeterminism of technologies to particular situations, whilst developing the mechanisms within which the pressures which inhibit or dampen the creative approaches of new technology could be eased. Furthermore, Mumford (1986) refers to the impact that a particular social structure can have on technical change and once effected how the consequent changes in structure modify further technical changes.

Recently there has been a growing indication that the link between technical dynamism and instability is acquiring a more prominent position in the theoretical literature. In 1986, Laszlo linked the theory of nonlinear thermodynamics with technical evolution by postulating that the new nonlinear theories could be validly applied to technology systems. This view was extended by Gordon and Greenspan (1988), who argue that technical forecasters should begin to deal with the nonlinearity of the systems with which they deal. The implication being that technical systems exhibited several different kinds of behaviour, from: (i) stability and the convergence to an equilibrium value, (ii) the illustration of oscillation in a stabilising cycle, to (iii) unstable and exploding technical characteristics. Silverberg, Dosi and Orsenigo (1988) and Silverberg (1988) extend the nonlinear analysis to provide a nonlinear economic foundation. This investigation was developed in order to understand certain questions concerning retardation factors associated with technical change in conjunction with the dynamic paths of change. The result has been a strong influence of nonlinear economic system interpretation concerning the link between the dynamics and the instability of technical paths (Dosi and Orsenigo, 1988). However, this research has remained theoretical and not been linked back to the possible implications of the new post-Fordist technical developments may have on industry in general and specifically on the firm.

There is growing indication and realisation, both in terms of practical evidence and theoretical research, that the new technologies of the post-Fordist era require a fundamentally new basis for understanding the problems associated with technical developments and the means to control any emerging instabilities. This overview presents the background to this a particular line of research enquiry. A definition of the systems based research is now given in section 1.2.

1.2 Defining the Research

This research is aimed at producing a system scientific model of technical change in order to provide both an increased understanding of the problems associated with technical developments, and an ability to control any technical instability resulting from a process of technical change. This model will be derived from three requirements: (i) the development of a systems based structure for technical change, (ii) the identification of the functional requirements which are essential to its process and (iii) the ability to provide a new interpretation of the effects of technical change, using a system theoretic framework.

In order to develop this model relative to these three requirements, this research defines a series of objectives which act as milestones for this research.

1.3 Objectives of the Research

The overall objective of this work is to produce a system scientific method for the identification and definition of a model which reflects the functional and structural characteristics of technical change. This will be achieved through three particular research stages in the systems theoretic framework. They consist of: (i) an analysis of existing technical change models, (ii) the development of a systems model of technical change and (iii) a rigourous evaluation and testing of the model.

The specific objectives of this research are:

(i) to analyse the current modelling procedures associated with technical change in respect of: (a) the reasons for the development of these models, (b) identifying the technical characteristics adopted in the models and (c) the structures used. This will help indicate the existing structural framework used in the analysis of technical change, introduce any specific functional aspects, and illustrate the specific problems which are described from the models of technical change.

(ii) To identify a relevant link between current modelling assumptions and the use of a systems based modelling approach. In achieving this, the systems based modelling approach will be able to extend existing assumptions concerning the nature of technical change with new insight obtained from a Systems Science perspective.

(iii) To develop a systems model which reflects the necessary structural characteristics in the process of technical change. This will provide the basis for identifying the mechanisms for reducing the problems associated with the implementation of new technology as well as help to define the diagnostic interpretations required for a systems explanation of technical changes.

(iv) In numerous industries, technical changes will have different effects on the various activities in each firm. The nature of this research attempts to identify and reflect certain similarities which exist between the mechanisms that govern the growth and development of different explanations of technical change. To extend the possibility for a unifying modelling framework, an evaluation of existing descriptions and explanations of technical changes, using economic and social theories in relation to the systems model, is to be carried out.

(v) To evaluate the systems model in terms of practical field research at a microelectronic based firm operating in a post-Fordist technical paradigm and affected by the problems associated with the process of technical change. This assessment will provide a practical orientation and test for the systems scientific model and help to illustrate its potential as a comprehensive model for explaining the managerial implications of technical changes.

(vi) To identify further areas for systems research in the subject area of technical change. The information obtained will help to provide an extension for the use of the system scientific model of technical change, both in a theoretical and pragmatic context.

The details of these o be carried out within the research framework outlined in Section 1.4.

1.4 Defining the Research Process

This research process is to be conducted in a system theoretic framework which describes the investigative process, and generates a system scientific model of technical change. Figure 1.1 presents a conceptual description of this framework.

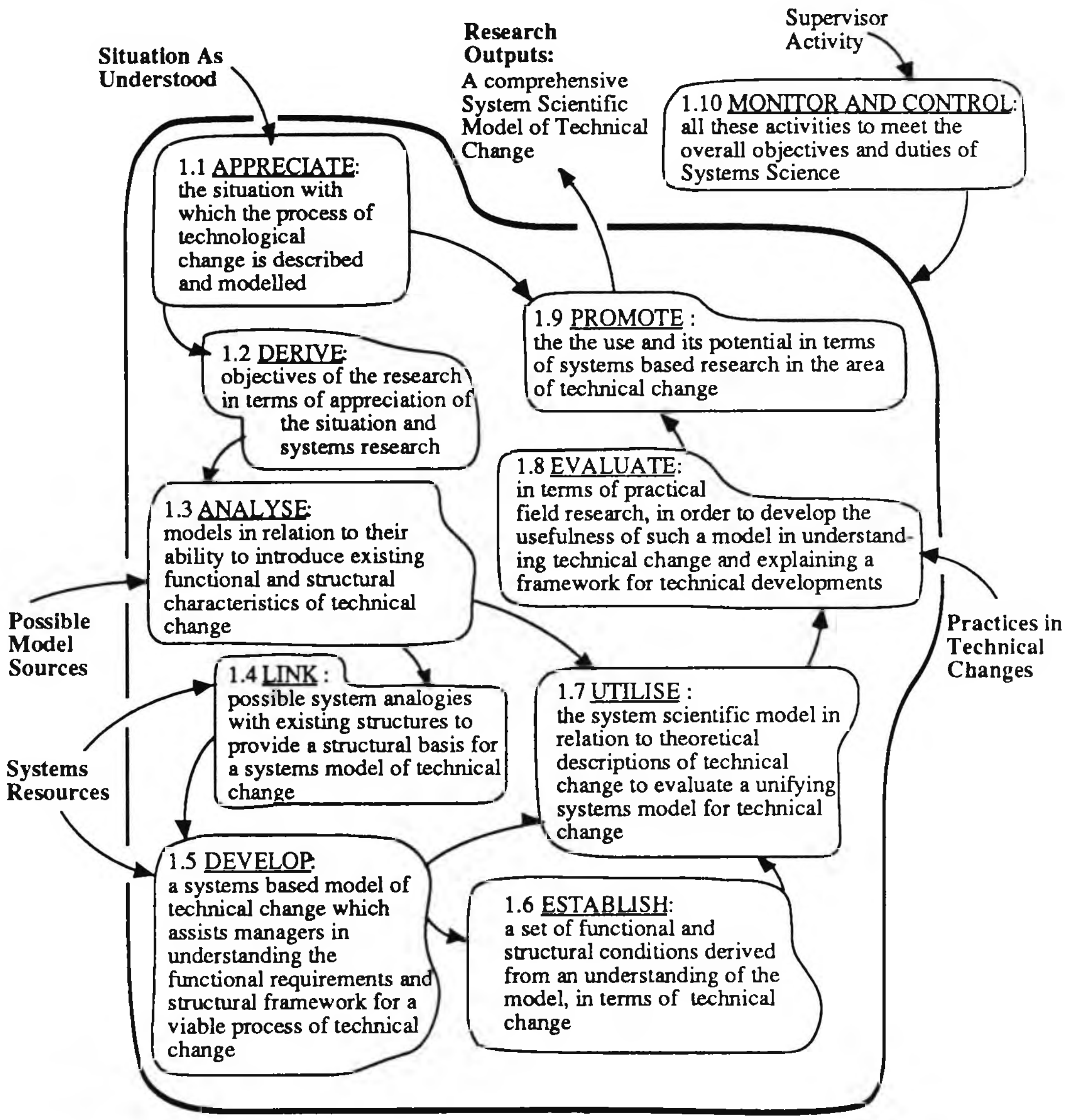


Figure 1.1 a conceptual system theoretic framework for the development of a comprehensive system scientific model of technical change

Using the research process identified in figure 1.1, the structure for this thesis is set out in Section 1.5, to form a summary of the arguments to be developed in Chapters Two to Eight.

1.5 Thesis Structure

This thesis is divided into three parts: (i) an investigation into the background issues for the development of modelling approaches of technical change. This analysis considers the functional and structural attributes which are used to describe, explain and predict the nature of technical change. (ii) The development of a system scientific model of technical change, using Beer's (1984) methodology of topological maps. This is used to produce a systems model which illustrates a set of functional and structured conditions and provides a reinterpretation of existing modelling approaches. (iii) A rigourous evaluation of this system scientific model in two application areas. The evaluation of the model is based on existing theoretical descriptions of technical change and a practical assessment of the model in a microelectronic firm involved in the process of a number of technical changes.

In Part One, Chapter Two reviews some of the existing modelling approaches for the description, explanation and prediction of technical change. It introduces the main issues involved in their design and development, and identifies the shortcomings that has kept all but a few from entering into practical business areas. Chapter Three examines in more detail the relevant issues associated with technical change structures introduced in Chapter Two. This identifies the prominent role of analogy in providing the main structural design assumptions for models of technical change. An account of the continued use of these analogies limits the possibility for developing a coherent structural framework for future models of technical change, using existing structural assumptions regarding technical change.

In the second part of the thesis, Chapter four describes a process for using a systems analogy to provide a coherent structural description for technical change. A number of system analogies are identified as providing a potential similarity to the structure of technical change. The adaptive whole system (Atkinson and Checkland, 1988) is analogically used to determine a systems based model of a structure for technical change by using Beer's (1984) methodology of topological maps. The structure developed, is theoretically examined and its limitations identified. Chapter Five investigates a more detailed systems analogy in relation to thc structure for technical change. A second pass through Beer's (1984) methodology of topological maps, produces a conceptual model of technical change, developed from assumptions contained in the viable system used in its analogical context. The model presents the structural framework and the functional requirements for a viable process of technical change.

Part Three deals with the evaluation of the viable systems model of technical change presented in Chapter Five. Chapter Six describes an evaluation process which is used to determine whether the model developed is a comprehensive system scientific model of technical change. This produces an assessment of the viable system model of technical change by analysing the existing descriptions of technical change through economic and social theories. Three evaluation stages are used so as: (i) to determine whether the viable system model of technical change fills a particular need in existing analyses of technical change. (ii) To identify whether the viable system model of technical change is an appropriate description of the process, in terms of existing economic and social theoretic interpretations. (iii) To illustrate how the model create a reinterpretive explanation of technical change. Chapter Seven extends this rigourous evaluation in a practical application domain. The viable systems model of technical change is assessed by analysing current practices within a firm operating in the European microelectronics industry. The conclusions from these evaluations illustrate that the viable system model of technical change can be classified as a comprehensive system scientific model.

Chapter Eight presents the conclusions drawn from this research work. The lessons for Systems Science are identified, and the possibility of continued systems research in the subject area of technical change is promoted. Background information concerning the activities of the microelectronic company, International Computers Limited is included as an appendix.

PART ONE

CHAPTER TWO

THE MORPHOLOGY OF TECHNICAL CHANGE MODELS

2.1 Introduction

This historical review studies the development of models concerning technical change, and reveals that any model of the process has generally emerged from a theoretical background, primarily focussed upon economic concepts, laws and theories. As a result, the desire to illustrate and describe the dynamics of the process has evolved primarily as an economic consequence to technical imperatives in which technical change has been frequently discussed as if it belonged to a single economic system operating to illustrate the variety of economic implications of technical change. Whilst the modelling of the process has been dominated by economic theory, further developments through theoretical isomorphisms and new insights have led to a proliferation of models which emphasise many different characteristics associated with the process of technical change, yet they generally have not had the practical successes of economic models.

Chapter Two is concerned with the how the structures in technical change models have developed from the dominating influences from both economic methods and other associated theoretical developments. The models are derived from a desire to interpret the implications of various technical change characteristics identified through technical diffusion, forecasting, growth and substitution. The principal aim of these models is centred around a determination to utilise an adequate descriptive or explanatory theory of change applied to technical developments. Whilst advocates of these models of technical change promote their predictive potential, there are critics who argue that any attempt to explain the process of technical change is fundamentally flawed as the prediction of its character can never be possible. This is because the unforeseen can never be explained, and therefore any description of technical change can only present historical understanding rather than make future predictions (Heertje, 1983). Such an argument however, does not exclude those aspects from an understanding of the essential characteristics in the process of technical change, but highlights the probable limitations of any explanatory or descriptive attempt.

It is the purpose of this review to provide a more informed understanding of modelling developments in the area of technical change. The aim being to provide a detailed information source, not only from the information generated in the models, but also their theoretical assumptions and methods of construction. This will form an account of the structural developments in those models which seek to analyse the processes of technical change. This will provide a necessary information source required for a modelling procedure which is to be developed from an appropriate prior theory and then translated into a new model which will attempt to provide an adequate interpretation concerning the processes of technical change. The discussion is presented in six main sections. The first, identifies models of economic growth incorporating technical changes and analyses the use of the production function and modelling via the concept of a fixed technology characteristic. The use of time pattern models is described in a second section, and covers aspects of technical substitution and diffusion. The following three sections illustrate particular types of models which utilise assumptions concerning uncertainty, engineering and stability characteristics. This illustrates the use of information economics, technical competition, the use of negative feedback models and the recent trend towards self-organisation models of technical change. The sixth section presents the use of conceptual models of technical change and describes the cognitive and cultural aspects associated with technical change. A summary of the general these characteristics and structures concludes this investigation on the morphological aspects associated with technical change models.

2.2 Economic Growth as a Model of Technical Change

The economic impact of new machines on the division of labour was first introduced by Adam Smith in 1776 (Smith, 1983). Rather than arguing that the development of technology should be considered as a 'gift of nature', Smith (1983) classifies these developments into capital saving or labour saving technologies. Ricardo (1971) extends these thoughts to illustrate how the impact of new technology affects the price of consumer goods and a shift in capital composition. These two factors describe how classical economists initially presented an interpretation of the impact of technical change, and included the endogenous factors which are inherent in the introduction of the new technology as well as the exogenous factors which operate independently from the new technology. Schumpeter (1928) expresses these economic concepts in terms of the production function. This conceptualisation was first introduced in terms of innovations resulting from exogenous forces acting upon a stable economy. Although Schumpeter's (1939) arguments shifted from the important relationship between the entrepreneur and technical change, to the important relationship between large industrialised firms and technical innovation, the general assumptions used by Schumpeter (1939), and particularly by the neo-classical school, subsequently led to the treatment of the production function with economic development and technical change as a somewhat similar issue. In this way, technical development could only be envisaged if new methods of production were involved and where factual observations of production and factors of production could be included. For Schumpeter, the model of the production function was to provide a mechanism which had the ability to describe the characteristics of technical change in terms of defining some form of static economic equilibrium. The structure of the production function is shown in figure 2.1, where proportions of capital (a) and labour (m) are used to generate yearly production profits (π). Technical change occurs through the changes taking in place in energy use and manufacture and distribution, but these changes can only be derived from the changes in the relationship between labour (L) and capital (K).

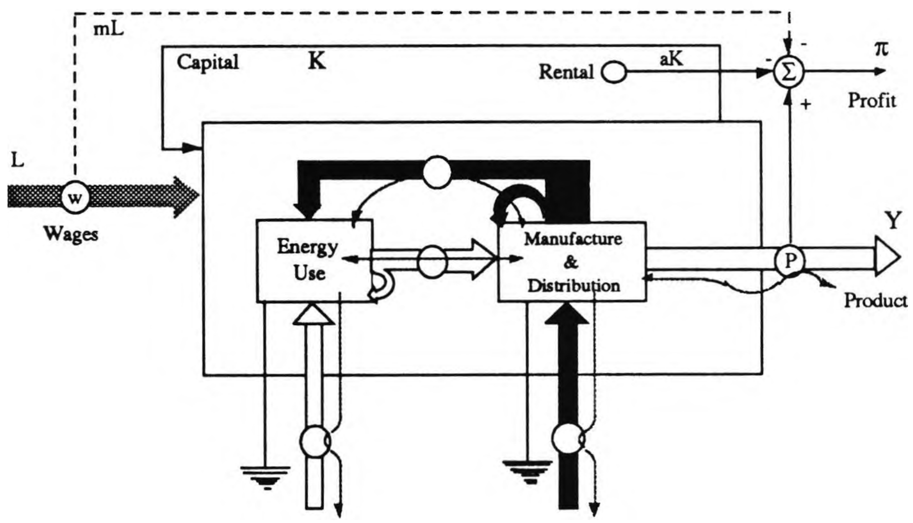


Figure 2.1 the production function model (M'Pherson and Limantoro, 1982, p. 27)

For some, including Straussman (1959) the model of technical growth did not provide enough explanatory information in order to determine the effect of technical change on business behaviour. Instead, the model was criticised as it was argued that technical change should be seen as a set of complimentary and mutually reinforcing developments, rather than simply through a static vision of production characteristics.

For the neoclassical economists, these assumptions provide the most appropriate framework to model technical change and describe a number of particular characteristics associated with such views. Neoclassical economics is based on the concept of the marginal utility, and assumes that producers and consumers can express their choice of technology by calculating their utility value. Further, it is assumed that the manner in which the utility changes is also known, but of most significance is the assumption that cultural attachments and motivations are excluded, other than that used for utility maximisation (Prigogine, 1986). Based upon this neoclassical view, technical changes emerge within the context of residual growth. This residual growth is defined as the economic growth which remains within the economy and is generally seen as the error values generated from economic statistics. This is identified through models which reflect factor changes in labour and capital. Yet this relationship between technical change and residual growth is often discussed as a circular one, and it is therefore possible, that such assumptions can only lead to the explanation of technical change by technical change!

Solow's (1956) model is based primarily upon the Cobb-Douglas production function, and emphasises that the concept of technical change is embodied through capital goods. These capital goods are used to link the state of the technology with the rate of the embodied technical change being dependent on the particular year of manufacture. Hence, technical change is assumed to be exogenously determined because of the model's reliance on a time function (Heertje, 1977). Secondly, the model incorporates factors reflecting capital goods as well as labour, through an embodied component, with the concept of education playing an important role. A number of assumptions, such as a single wage rate for each year together with a homogeneous market enables the model to demonstrate how labour is distributed over the initial manufacture of the capital goods. Yet these aggregating assumptions have led to criticisms that there is not much actual differentiation between labour and capital goods because there is a strong technical relationship between the two (Heertje, 1977). Further, wage rate assumptions assume a particular interest rate position, one that is exogenously determined and where the technical switch point tends to be determined by the rate of interest.

The main difficulty in adopting a production function model stems from how an interpretation between productive characteristics and technical possibilities can be made. The consequence of the use of this model is that it can only be effectively used to illustrate the application that a new technology has upon a firms production capacity. Assumptions concerning whether technical change is an endogenous characteristic or, is still an exogenous force in a mainly economic growth model, produces even closer examinations of the factors influencing the shift in the production function. Kennedy (1964) assumes that technical change occurs when at least one factor of production decreases in percentage terms, and he uses these factors of production to plot an innovation curve which includes such aspects as: (i) labour and (ii) capital cost to describe two possible types of technical change. In this respect the change does not result from a difference in prices, but on an analysis of technical possibilities and these characteristics are illustrated in the Kennedy-Weizsäcker model of induced innovation (Heertje, 1977). McCain (1974) extends the use of the model by incorporating product innovation which demonstrates the bias effects on induced technical changes.

Nordhaus's (1967) production function model assumes that the nature and rate of technical developments are dependent upon the financial resources available for research and education. In Nordhaus's (1967) model, change is not solely derived from wages and production costs but on the allocation of manpower to technical development. Shell (1974), in a similar approach to that presented by Schumpeter (1928), treats technical change as a function of production, but goes one step further. Rather than assume that the act of invention is exogenously determined, Shell (1974) assumes that the act of invention is treated as part of the production process and therefore is contained within its own production process. The two models of Nordhaus (1967) and Shell (1974) indicate a noticeable movement away from models which describe the exogenously derived technical change and more towards endogenous technical developments.

Two further examples which reveal a similar trend in modelling technical change are given by Uzawa (1965) and Phelps (1966). Usawa (1965) constructs a model which derives technical development from a function of the level of employment in an education sector of the economy. Still based on the production function model, it incorporates aspects which are concerned with percentage change in employment in education and with employment within the non-education sector. A number of models developed from this line of enquiry, particularly from the work of Phelps (1966), takes the diffusion of technical knowledge into account as well.

The most acute problem with this type of modelling is that once involved in a growth model it is impossible to determine why technical possibilities expand because the model developed does not consider those aspects of mutation and selection, rather it considers the effect of technical change solely on the growth of the production characteristics.

2.21 Using the Micro-Economic Production Function Model

Much of the economic difficulty in modelling technical change arises from this reliance on a production function being defined through the notion of residual growth in capital and labour. Heertje (1983) describes the acceptance of a production function variable as somewhat speculative, particularly in the modelling context in which it is used, and partly as a result of assuming that the function reflects the state of the technology exclusively, as seen through a static analysis. Although these production sets (Heertje, 1977) can be regarded as technical data, it is impossible to ignore the possible formation of new production sets which can be derived as a consequence to a dynamic analysis. The problem is that dynamic analysis is much more difficult to interpret with the result that micro and macro dynamic assumptions appear to interact to present an incoherent dynamical explanation of the effects of technical changes on the firm or an industrial sector.

The macroeconomic production function is a generalised variable, and hence, suffers from all the problems associated with modelling through generalisation, that is, the information which is generated suffers from a generality and tends, therefore to lack significant content. Whilst, the microeconomic production function does correspond to a relation between production and the means of production, it does so without specifying how it is derived. In this case the microeconomic production function, at best, appears to be introduced as a simple analogy to macroeconomic discussions, but without any form of reasoned argument. Thus, two factors tend to be transferred across from macroeconomic to microeconomic analysis, these are: (i) In the use of the production function, the variable is used within the economists models as a mechanism which is to be optimised and consequently the process of technical change is described as an optimising phenomena. (ii) Any model of technical change which is reflected by a shift in a production function variable at the microeconomic level, is assumed to be reflected as a direct result from any change in a given technology. However, the actual consequences may be due to factors which lie outside technical developments, the simplistic assumptions which derive from the movement of macroeconomic information to the microeconomic level tend to provide an incomplete picture of technical change.

Neoclassical economists argue that changes in technology emerge as a result of a new production function, and one that can not be derived from a previous iteration of an existing production function. This is mainly because the assumptions concerning the new technology rely upon a totally different set of production characteristics. The shifts in the production function which are caused by changes in prices are assumed to indicate economic rather than technical development. Heertje (1983) maintains that this illustrates an essential contradiction in the types of model used to describe technical change through an emphasis on the production function characteristics.

The argument which is used by the Neoclassicists, state that a new production function cannot be derived primarily from the existing function, as the new incorporates a new set of technical products and processes, not present within the old framework. The strength of the production function model is seen in its continued use as a mechanism for description rather than as an explanatory device. Boulding (1983) refutes such an argument, by maintaining that technology itself has an evolutionary characteristic akin to that of human learning. Boulding (1983) assumes that the process occurs through a continuous medium which is developed through both incremental and radical movements forward, and developed by means of adaptation and selection. However, the production function models do not illustrate the forward motion accurately, rather they assume that the process of change can operate in more than one direction. As far as Laszlo (1986) is concerned, this evolutionary process of technical change is an irreversible function, and one that should be incorporated into microeconomic models.

These issues present a constraining factor for the description of technical change within an economic modelling framework. The variables used seem to get lost in the function which solely emphasises technical developments through changes in the quantity of production (Cohen and Halperin, 1986). Hence, the production function is information limited insofar that it is used to model the process of technical change through changes in labour and capital costs. Further, Cambridge economic theorists regard neoclassical economics as being fundamentally flawed, because of the reliance upon equality and homogeneity within competitive marketing assumptions, this being coupled with the assumption that the method of measurement for the technical change process is approximated by production values, is considered to have severe limitations (Smith, 1973). These theorists argue that the interaction of all the mechanisms which govern the economy must be considered as influential in technical change and therefore must be included in the choice of the model which is used to represent that process. In essence, they question the legitimacy of using a production process to describe technical change through the existence of an aggregate function, and secondly, question the importance of employment and the equilibrium value (Smith, 1973).

Advocates of the production function put forward the counter-argument that technical change is merely a consequence of the production process, and that this can be seen as an unwarranted aggregation by opponents to this view. Economic theory deals with this through characteristic generalisations or through over specialisation, where these models merely represent a partial understanding of a process that is accompanied by the unanticipated consequences resulting from changes in technology (Carvajal, 1983 and, 1985). Further evidence of neoclassical thought and the use of the production function variable is provided by Smith (1973) who states that many economic models of technical change appear to be founded on a theory of wages and on perfectly competitive market conditions. This is achieved by relating labour and capital coefficients to an economic desire for a maximisation in the rate of decline in unit costs of production, which are implicitly regarded as a technical change. Ironmonger, (1983) suggests that these economic models are built on the assumption of a fixed technology that is, by using a continuous production function which shows that any changes in technology can be reflected in the variations of prices and incomes. These models are not primarily based on the direct economic implications of technical change, but on how the changes in prices and wages affect consumption patterns and therefore indirectly reflect the changing characteristics of the technology.

Numerous models have been based upon neo-classical theory, which uses the concept of the production function. However, the tendency is for such models to be ineffective in their attempt to explain the process of technical change. Generally it is possible to conclude that this is due to the lack of a particular means to determine a set of initial conditions for these models. This is compounded by its relation to the assumption of a perfectly competitive market place used in these classical economic models of technical change. The result illustrates that the simple connection between the two factors of labour and capital are wholly inappropriate for the adequate modelling of technical change. These descriptions, derived through the characteristics of the means and factors of production associated with the production function model, provide an anomaly between the model and what it attempted to describe. This was emphasised by Mansfield (1968) who sought to extend these existing limitations by introducing into the modelling framework concepts of: (i) profitability, (ii) economic uncertainty, (iii) technical performance and (iv) economic commitment. Although many production function models emerge, they continue to remain within the mainstream neoclassical school and persist in using economic production theory to explain the process of technical change.

2.22 Modelling Through a Fixed Technical Assumption

The assumption of fixed technology is generally reflected in models which describe the employment consequences of technical change. The argument is concerned with the structural stability associated with the characteristics of the technology under consideration. In the case of the production function model, although the production sets may differ with the development of new technology, their structural characteristics are invariant. Similarly, changes in technology are often illustrated by indicating the changes in the Gross National Product (GNP), labour productivity measures and research and development expenditures, rather than a change in the technical description. Specifically, this type of modelling is normally seen in models which attempt to link employment changes with technical developments. For example, Venebles (1985) identifies the resulting unemployment through a coefficient of technology built on a theory of prices and wages within an economy, illustrating that the type of unemployment derived from changing technologies is dependent upon the ratio of these particular variables.

Clark (1980) also uses a fixed technology model in order to simulate employment consequences. It is based on a theory of wages and a profitability function to describe the process of technical change. Rather than describe the process of innovations, Clark (1980) attempts to analyse the effect of technical diffusion on changes in employment levels in a manufacturing sector, developing within an economic system. The emphasis in this model is predicted upon the assumption that changes in technical productivity are based on radical or incremental changes in the technical characteristics rather than on a change in the type of characteristics used within an industrial sector. Therefore, the characteristics of technical change within the model are reflected by the structural relationship between labour/output ratios, capital/output ratios, profitability and time lengths of the technologies being considered. Changes in productivity levels allow for variations in the nature of the technical change within the overall framework of a stable structural system description.

Hopkins and Hoeven (1981) also provide a simple economic system model, which contains one single product. Its aim is to help discussions of the effects of technical change on employment and other related issues. Rather than looking at one sector of new technology this model attempts to analyse both supply and demand factors. This model does not consider export or imports, and only two types of labour are considered. These are: (i) labour which increases with the introduction of new technology and (ii) labour which decreases with new technical introductions. A production function is used which relates investment to increases in output which is augmented by technology factors. Other factors include: (i) consumption, (ii) demand, (iii) labour supply, (iv) population, (v) unemployment, (vi) income distribution and (vii) surplus capacity. The conclusion reached is that the introduction of new technologies should take place in a situation of supply-demand equilibrium, or even excess demand.

This is the general format for most fixed technology models. In particular, Sahal (1979a, 1979b) represents technical change through a specialisation via scale hypothesis utilising two variables. The first variable is a measure of technology in terms of size, or speed. An equilibrium growth value, defined by Sahal (1979a) as an experience value, is determined by a ratio between a dependent and an independent variables. Figure 2.2 depicts relationships between dependent and independent variables. Here the fuel consumption efficiency in tractor technology is the dependent variable, with the average acreage of farms being the independent variable.

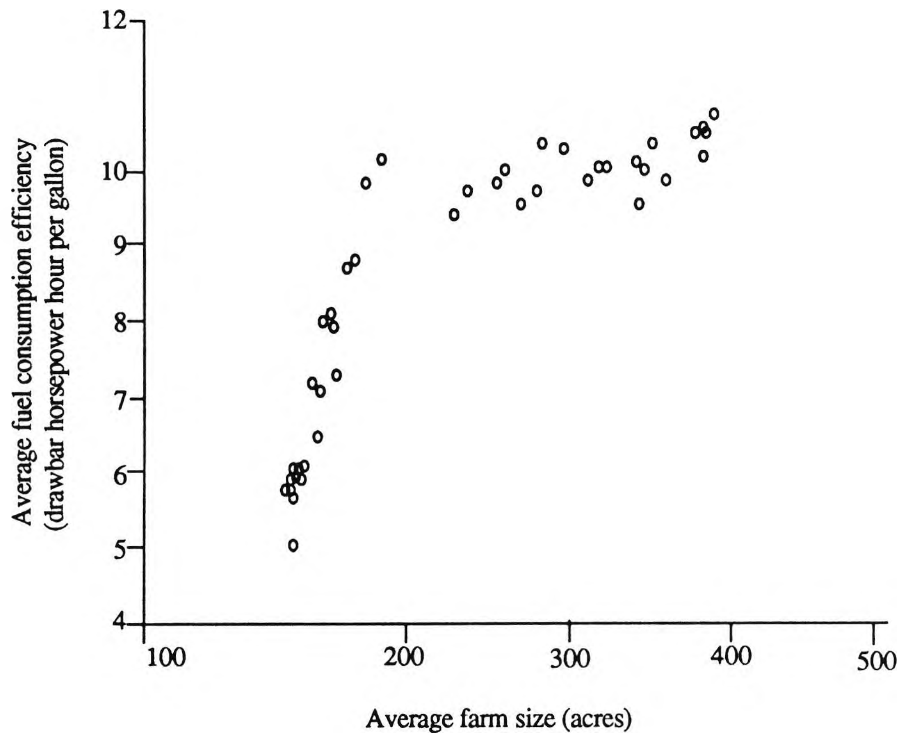


Figure 2.2 Relationship between fuel consumption efficiency of farm tractors and average farm size, 1921-1968 (Sahal, 1979a, p. 270)

A model is developed using this information, together with the extension of the Gompertz equation: $Y=Ke.^{[-e^{(A-Bt)}]}$, to develop a theoretical description of technical evolution. Sahal (1979a) develops the model by assuming that it reflects the notion of system size. That is, a technical system size is used by measuring accumulated experience and utilisation. Secondly, the size of the physical system which surrounds the technical system, measures use the magnitude of the technical achievement. Using the characteristics of the Gompertz equation, Sahal's (1979a) model illustrates that technical development is governed not only by the history of its technical system but also by the scale of its physical operations.

Sahal (1979b) hybirdises the model of technical change which is developed through two motives for technical change. These are: (i) a profit motive and (ii) a technical motive. The technical motive is derived, for example, through equations which correspond to fuel consumptions and mechanical efficiency. The profit motive enters the model through price ratios.

Sahal (1979b) argues that the problems with other economic models of technical change are that they are generally beset with assumptions concerning labour saving bias, and the viability of the models can only be justified by the neoclassical assumptions relating employment conditions to technical changes. Sahal (1979b) goes on to argue that acceptance of the results of these types of neoclassical model can only be acknowledged if technical changes can be identified with: (i) a lack of calibration for initial conditions, (ii) a fixed capital output ratio, (iii) assumptions of perfectly competitive markets and (iv) the withdrawal of pricing regulations. He suggests that, in short, the most serious defect with economic models of technical change is the tendency to model the process through autonomous production system assumptions. This can be further emphasised through a model developed by Link (1976) which is used to illustrate the induced innovation mechanism within technical change. This model assumes: (i) perfect knowledge, (ii) a homogeneous nature of the labour market, (iii) optimal use of new technology and (iv) factor price ratios playing a constant role. These assumptions are all linked into a linear homogeneous production function operating through changes in the labour force used in the production process, the capital already employed and the latest capital unit being added to the production process. Changes in technology are described through a parameter which illustrates the dynamics of technical change through output variations. The benefit of such a model, according to Link (1976), is that the theoretical concepts of neutral and non-neutral technical change can be incorporated into the model and used to illustrate the hypothesised relationships between labour, capital and factor saving technology. Other questions concerning: (i) the regional technical differences, (ii) the induced nature of technical change, (iii) the relationship to entrepreneurial decisions and (iv) research and development activity were not considered. However, Link (1976) maintains that this particular model could be useful in answering these as well as other related technical change problems.

The simple connection between the two factors of labour and capital within the production function and technology cannot be appropriate for a comprehensive modelling account of technical changes. However, identifying the problem that the production process can only be a partial representation should not exclude the possible contributions that may be generated by trying to understand some of the essential economic aspects which are associated with the process of technical change. Such contributions already accept the limitations of using the traditional production function model and attempt modelling adaptations under the basic economic framework.

Cohen and Halperin (1986) introduce an extended model of the production function within the boundaries of the neoclassical school by utilising characteristics derived from Mansfields (1968) work. The model utilises decision making criteria by relying upon various economic characteristics within a production process. It treats production and technical choice as the same issue, and links production planning and technology selection in a direct manner. The decision criteria computes changing demand patterns in relation to the production plans of the firm, and links this with the course of evaluating the costs and benefits of implementing possible new technologies. This is achieved through the selection of identified technical choice sets based on a maximised profit utility. Although initially represented as a static model it is built into a dynamic decision model by relating a discounted profit with a decision horizon. The conclusions reached indicate that the resulting new technology decisions are principally based on the lower variable costs of the technical alternatives, given a high growth in demand. However, the switch depends on the probability distribution of demand and the ratio of fixed costs to contribution margins.

Similarly, Homer's (1987) diffusion model of medical technology addresses both the adoption and the changing extent of the use of an evolving, product based technology by analysing the changing parameters in a fixed technology assumption. The model illustrates a strong static structure but is used to provide the foundations for a system dynamics interpretations. Three functional areas exist in this model: (i) technical uses, (ii) technical support and (iii) technical evaluation. These key areas in the model consist of a number of variables which are endogenous to the technology. These include aspects of: (i) purchases, (ii) technical adoption, (iii) extent of technology use, (iv) actual technical performance, (v) observation and reports, (vi) perceived performance and (vii) promotional marketing and (viii) product modification.

Exogenous factors are also included, for example, aspects of Government intervention, initial conditions and times of technical replacement.

An analysis of Homer's (1987) assumptions concerning technical adoption reveal that the structure is based on a uniform link between an acceptor fraction and a purchaser fraction. The general features of this section of the model are described in figure 2.3, and describe the particular relations held between the variables in the model.

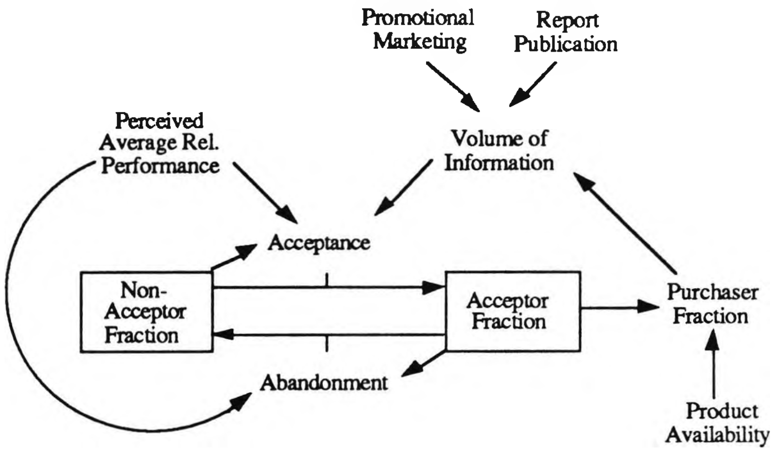


Figure 2.3 technical adoption sector (Homer, 1987, p. 204)

Other aspects of the model, such as purchases, are derived from an analysis of relationships between new or replacement technology. This particular information is built up by calculating the extent of existing technical use, coupled with a technical selection mechanism. The derivation of actual technical performance is generated from a comparison between expected benefits and expected risks which are determined through the extent of use, skill and product capability. Technical uncertainty surrounding new technology adoption is developed from evidence in reports and observations. The two other key variables consist of planned promotional marketing and planned product modification, both of which are determined by sales revenue.

The model was used to analyse the development of two different studies in medical technology, concerning the two technologies of pacemaker implantation and the introduction of the new clindamycin drug. The simulations obtained from this multiloop diffusion model were shown to correspond closely to the actual results obtained from physicians with regard to: (i) their attitudes to adoption, (ii) patient selection and (iii) factors affecting technical performance.

The implication is that the model could not only be used for the analysis of the evolution of medical technologies, but as Homer (1987) points out, the generic structure of the model might prove useful in the analysis of other technical changes in other contextual situations. Extensions to the model could be developed by introducing endogenous technical costs and prices which in the present model are assumed exogenous. The implication of this extension is to introduce a price variable in the purchasers decision making procedure and the diffusion of more than one technology whose uses are interdependent.

2.3 Time Pattern Models of Technical Change

Although the application of economic theory with respect to technical change is primarily derived from the characteristics of the production function and based on Schumpeter's (1939) assumption that a close link existed between economic growth and technical development. The link is not exclusive to economic criteria, with the characteristic economic or technical cycles being strongly related to the time pattern logistic sigmoid curves of population growth. Rothwell (1985) states that Schumpeter's interpretation of the long term cycles in economic activity through the introduction and diffusion of new technologies, could also assume that technical activity would exhibit a kind of cyclic behaviour similar to that described by the sigmoid curve. These long wave models of economic growth are synonymous with technical change, but with the use of the sigmoid curve models there is an improved ability to specifically interpret the effects of technical substitution and diffusion.

An important benefit derived from using this type of sigmoid shaped model lies in the successful application of different sets of technical data through substitution analysis. This can be interpreted using biological theories concerning the diffusion of a population within an ecological niche. Mansfield (1968) illustrates the process of technical change through the diffusion pattern of a sigmoid curve using a variable reflecting the numbers of users of a particular technology. Other measures include: (i) values for interfirm diffusion speed and, (ii) proportion of output produced with the new technology. Stonemann (1983) maintains that most of the sigmoid curve models rely on an interpretation of the demand side of the diffusion process. On the supply side, Stonemann (1983) reviews the work of Gaister (1974) which relates interfirm diffusion speed to a price function which users pay for goods embodying new technology. The result, according to Stonemann, is that if profitability remains constant a logistic curve can be produced. If the profitability changes, the growth curve remains sigmoid but develops a positive or negative skew.

Many of the models of technical change which use substitution and diffusion assumptions to analyse technical change behaviour are based upon characteristics derived from the sigmoid curve. The main impact of using these sigmoid curves or 'wave' models, is suggested by Businaro (1983), to provide a means of analysis which interprets technical changes within three particular phases of development in an industrial sector. These are in the phases of: (i) product innovation, (ii) maturity, and (iii) incremental process innovation.

Isensen (1966) argues that the basis of technology is solely derived from knowledge and information. As such the 'state of knowledge' constitutes a value for technology with the rate of change of knowledge reflecting any technical changes. The model uses the basic framework of an sigmoid shaped curve using variables such as: (i) number of scientists, (ii) the average productivity factor and, (iii) time. Jantsch (1967) describes the Hartman (1966) model of technical change which uses similar characteristics to Isensen (1966). This model relates changes in information and the number of scientists to the rate of change of technology. The model results in the characteristic sigmoid curve. Yet both of these models rely on the assumption that information gain is proportional to the amount of existing information. This provides an equilibrium structural basis for the model and hence, the similarity to the sigmoid shaped curve.

The ability to forecast any technical changes has developed around the use of this sigmoid curve but with the use of variables concerned with technical data, such as: (i) substitution rates by Fisher and Pry (1971), (ii) market share by Blackman, (1972) and (iii) profitability indexes by Mansfield (1968). According to Sharif and Kabir (1976) the reliability of these models has been increased by: (i) the scatterness effect of the historical data, (ii) the number of observations in terms of time and magnitude, (iii) the effect of the last data point and (iv) the effect of the technical product life cycle. Other models of technical change which use the sigmoid curve as their structural basis for analysing technical substitution have been: (i) the Gompertz curve (Sahal, 1979b), (ii) the Fisher-Pry (1971) model, (iii) the Blackman (1974) model, (iv) the Stapleton (1976) model, (v) the Sharif-Kabir (1976) model and (vi) the Weibull distribution model, developed by Sharif and Islam (1980).

Apart from the Weibull model (Sharif and Islam, 1980) and Sharif-Kabir (1976) model, all have a fixed inflection point and illustrate symmetry around that point. The description of technical change is then limited by this assumption of symmetry and the fixed inflection point. With this generalised assumption, these models describe a technical growth or diffusion that maintains that the same rate of growth, where the period of maximum rate of change occurs soon after the innovation has been recognised, for all technical products. The Weibull distribution model, illustrates technical change in a wide variety of situations. The probability density function of the model is interpreted as a change rate of technology, with the function acting as a fraction of the upper technical limit achieved with respect to time. Its potential benefit is that it can be used to predict technical growth as well as technical substitution and diffusion. That is, it can be regarded as a general technical change model.

2.4 Modelling Uncertainty in Technical Change

The relationship of business cycles of economic growth to the characteristics of technical change marks an increasing movement towards evolutionary modelling of technical developments. However, the continued use of the production function model has been to highlight the benefits of using aggregated values of economic criteria in descriptions of technical change. Emerging out of this historical trend has been the tendency to remain within mainstream neoclassical assumptions, that is, technical changes develop and take place within the boundaries of production systems. Using this existing format for modelling technical change, economic values have been used to advance such approaches by the development of decision analysis frameworks, based upon information costs for evaluating any emerging new technology. The consequence has been a rise in the number of models which attempt to derive some formulation concerned with modelling the reduction in technical uncertainties.

2.41 Information Economics and Technical Uncertainties

McCardle (1985) treats the process of technical change as a catalyst of economic profitability, and although the concept of technical changes may be lost in the 'worth' notion of profitability, it is used as an indicator for quantifying information uncertainty with respect to the profit potential of a new and emerging technology. This model, which is based on Schumpeter's (1928) entrepreneurial theory of technical change, extends the use of the production function as a simple model and introduces a degree of decision analysis into the economic model through the use of the Bayesian theorem. Hence, the problem of modelling technical change is moved away from the actual understanding of the process, to an economic decision model. This is used to estimate and decide upon the adoption of new technology, through the continuous update of profitability estimates by the amount and cost of the information gathered. This is shown in figure 2.4.

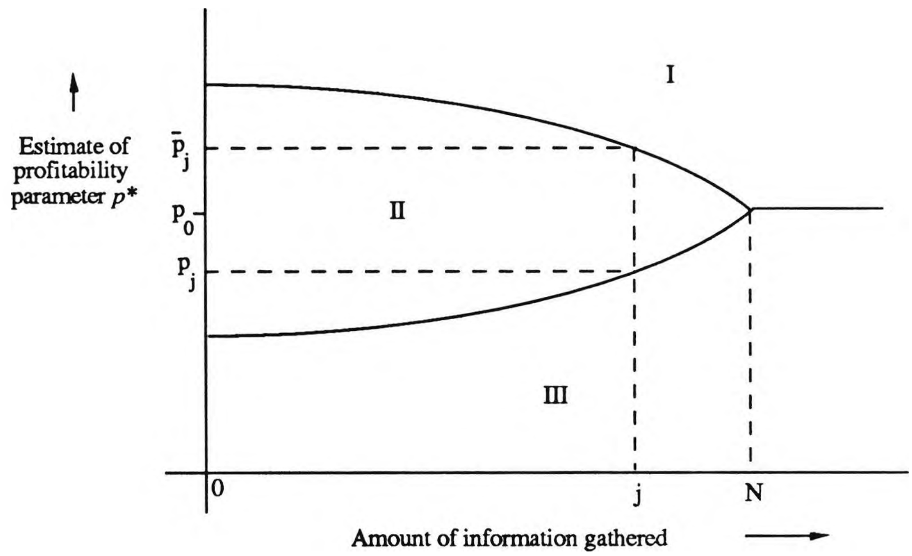


Figure 2.4 a link between information gathering and profitability estimates of new technology (McCardle, 1985, p. 1374)

The diagram shows how a firm starts with a profitability estimate, p, and by gathering information causes a shift to the right. Upward movement reflects favourable information and downward movement reflects unfavourable information. Information gathering continues in region II, whilst the firm should reject the technical change in region III and adopt the new technology upon the arrival in region I.

The focus of this model is on understanding the flow of technical information in the area of economic implications for new production processes. The primary assumption in this model is that all the information gathered is related to a technical profitability parameter. The criteria for the use of that information is not the content of the information, but the cost of information gathering relative to an interest rate function, and the cost of the purchase of information. Whilst the model is valid within a specific range of economic assumptions, an analysis of the model reveals that the occasional adoption of unprofitable technologies can occur. An explanation of this fact is derived from the problem of dealing with the uncertainty of technical change which extends beyond the decision analysis criteria. This can be understood by considering an adoption which is caused through uncertainty inherent in the technical change and the costly nature of technical acquisition, rather than in the economic information derived from it. This is further undermined by the economic conceptualisation of technical change via the inherent uncertainties of information content, lack of competition and any further technical innovations.

On a similar foundation, Pope and Hauptman (1988) derive a model which illustrates the need to evaluate the potential of an emerging technical product. The model is derived from assumptions concerning the economic interpretation of information acquisition. The information is classified by using economic variables of market opportunity and profitability, coupled with the assumption of linearity between these two variables. The model is based within a decision framework which operates in order to reduce the uncertainty surrounding a new and emerging technology, and proceeds through a series of sequential operations based upon Bayesian decision rules. The model attempts to quantify the technical uncertainty derived from learning and budgetary constraints, as well as the cost of search (finding out) and research (in house experimentation) with respect to the new technologies. The model is used to construct an optimal estimate of the economic opportunity over a particular horizon for a new technology. The emphasis is upon a process orientation, and built on assumptions of decision making criteria concerning information searches used through a scanning function on new technical activities. The decision maker faces three possible decisions when faced with a possible technology change. These being: (i) whether to continue gathering information concerned with a new technology or not. If the requirement is to stop the acquisition of information the decision has to be concerned with (ii) whether it is appropriate to adopt the new technology or (iii) to keep an existing technology. The empirical nature of this model is generated from a reassessment of the probability distribution between the economic cost of information acquisition and uncertainty of the new technology. Within the context of an economic system, this model provides an interpretation of managing technical uncertainty through an economic learning process.

The use of linear relations is not uncommon, Sullivan (1986) advocates the use of linear additive models that can aggregate information so as to include non-monetary factors in the strategic decision to adopt new technology. The model is characterised by the use of weighted values assigned through a decision criteria and is used to reflect the performance of new technology through the attainment of the decision criteria accepted by the firm. The criteria is used to build a model which can reduce information uncertainty and hence introduce a form of stability from which a decision can be formulated concerning the nature of technical change within the firm.

2.42 Uncertainty and the Nature of Technical Competition

Reiganum (1983) introduces competitive elements in a game theoretic model which presents an important insight in the description of technical uncertainty. In this model, the competitive element is dealt with by the uncertainty in the information content of competitors actions, and utilises economic criteria for representing imperfect but complete information. The model is developed from from a two person game theoretic version of a production technology search, developed by Reiganum (1981), and uses production costs through the maximisation of expected profits and the minimisation of search costs. The information is used in the context of an uncertain profitability and the output from the model is a description of the effect of technical actions between rival firms and upon the firms' decision on whether to adopt or reject a new technology. In Reiganum's (1983), paper the technical uncertainty is considered as strategic, and although the behaviour of the competitor is unknown, by the end of the game this is resolved. Within this outline, the output of the model is to a large extent a result of its assumptions of short and long term reductions in production costs as a result of the new technology, as well as the operation of rival firms in a homogeneous market. Stonemann (1983) also states that in Reiganum's (1981 and 1983) work, the technical assumptions are that it is always possible to make more profit using a new technology as opposed to an existing one, and that the profit will be greater, the earlier the new technology is adopted. Both of these assumptions are arguable and it is possible to extend the game theoretic model to include economic parameters which link economic profit not simply to the introduction of a new technology, but also to existing production characteristics, market mechanisms and demand factors.

Specific to Reiganum's (1983) model, is the emergence of two forms of uncertainty: (i) an uncertainty of unit cost distribution between the rival firms and (ii) an uncertainty which reflects the differences between implementation and adjustment costs of the new technology in each firm. The model generates a set of probability values for particular forms of strategy, but it keeps within the bounds of neoclassical assumptions of production costs and profit values. The model illustrates characteristics which are based on the problem of generating perfect information in the provision of an optimal estimate which a new and emerging technology might provide. This is achieved through the in built assumptions of market opportunity and profitability. What develops from the hypothetical model are three derivations of 'Nash equilibria', which particularly highlights that a high production cost firm is more likely to change existing technology while a low production cost firm will not change, irrespective of the competition. Further, the model illustrates that technical diffusion paths do exist, and that although firms may appear to operate the same technical strategies, the 'Nash equilibria' for each firm does not have all firms adopting technology at the same time (Stonemann, 1983). The impact of the model is that it provides some insight into the importance of scanning competitors actions.

Based on Reiganum's (1983) working model, Mamer and McCardle (1985), develop a model which also deals with the problems of economic uncertainty with regard to competitors actions towards technical change, as well as the uncertainty of new technologies themselves. The model, examines the sequential gathering of information in order to generate an profitability estimate in a Bayesian fashion. This is subsequently depicted on a profitability distribution curve. In many ways it is of a similar construction to the model of Pope and Hauptman (1988), but is used for gathering technical information and for information on competitors actions as well. These models are described by Ironmonger (1983) in a second economic category which assumes a changing technology model. Within this second category the primary concern is to generate an explanation of the rate of adoption of new products and processes. Producers are described in the model by the activities of finding out about new technical products and processes, and illustrates how the producers would adopt them as soon as advantages were discovered and understood. The focus of attention is placed upon the generation of product information developed through the construction of the model and economic information is clarified in order to provide an optimal adoption strategy for new technology.

2.43 Technical Creation through the Reduction of Uncertainty

At the core of the systems view of technical change is the concept of its holistic nature, characterised through the notion of technical creativeness. The modelling description for this creative characteristic in the economic process of technical change does not arise primarily from the production function or profitability parameters, but from the notion of modelling economic uncertainty. This uncertainty is introduced through the economic assumptions of imperfect information identified by: (i) McCardle (1985), (ii) Cohen and Halperin (1986), (iii) Pope and Hauptman (1988) and (iv) Sullivan (1986). In addition, the introduction of the competitive aspect in models of technical change does add an important element of progress in the process of modelling economic uncertainty in this area. Noticeably, all these models are based upon the economic assumptions of stability and equilibrium.

2.5 Models Described Through an Engineering System

Clark, McLoughlin, Rose and King (1988) discuss assumptions surrounding technology as an engineering system, and hence they assume that technical change can be represented by models using engineering principles. The basis is to model technical change through the theoretical assumptions of an engineering system, whilst using economic information to reflect those engineering principles. Jones and Tanchoco (1987) describe the impact of technical change upon the problems derived from machine replacement, and consider such impacts through changes in: (i) efficiency, (ii) reliability (iii) productivity and (iv) with the changes to initial and operating costs of any new technology. The effect of the magnitude in the technical change is determined through variations in opportunity costs and salvage values. Therefore, the model integrates both engineering principles of reliability and efficiency with economic characteristics of opportunity costs, salvage rates, operating costs and even tax analysis in terms of depreciation of the new technology.

Bean, Lohman and Smith (1985), incorporates a similar theoretical background to the development of a model, which utilises a value function incorporating the potential cash flow and time horizon for a particular new technology. The emphasis is upon simulation of a net present value with variations in productivity levels which are assumed to function through a bounded exponential function and determined through a rate of technical change and the corresponding size of the change. This use of an economic base to model engineering assumptions is also presented by Swamidass (1987). The basis of this model is used as a comparison mechanism between an existing technology within the firm and a 'state of the art' technology. The emphasis is upon engineering principles, with indices used to reflect: (i) technical deterioration, (ii) quality and (iii)flexibility, which are subsequently used to simulate a technology curve.

Another engineering model which uses an indices measure to analyse the process of innovations is developed by Evans and Mantel (1985). Their model generates a value-weighted productivity measure, by evaluating individual elements within the existing production process which might be altered by a new technology. The evaluation centres on a particular technical innovation, and while this engineering information is generated, a sensitivity analysis is performed in order to find those elements which can be considered most influential in any possible change process. The benefit of such a model is based on the early evaluation of the technical development which might prove economically unacceptable to the firm.

In 1977, M'Pherson (1977) presented a conceptual approach to the overall process of technical change reflecting similar views expressed in Harrison's (1986) integrated model. The consequence was the development of an Integrated Model of Technical Change (IMTC). This was specifically designed to produce an socio-engineering model of technical change, by providing a means to: (i) study the overall mechanisms of technology change as a whole, (ii), forecast feasible technical changes, (iii) provide a decision model and (iv) provide a computed input of technical change to world models, forecasts and plans.

These four elements describe the foundations for the model, and include aspects for, society, decision makers, engineering and industry and the natural environment. The IMTC was developed into three sectors consisting of a basic technology model, a technical change generator and satellite models. It was designed to be complimentary to existing economic models by extending the economic production function model, so as to include engineering assumptions concerned with resource conversion and thermodynamic constraints. The model uses technology state vectors and efficiency values for techno-sectors, which integrate information derived from economic models and health and education models. The assumptions reflect a resource flow model which is primarily concerned with energy flow for each technical conversion.

> "... the IMTC is concerned not with the actual production of a techno-sector at time t, but with what it could produce given its technical state and the quality of available resources."
>
> (M'Pherson, 1977, p. 5)

Operationalisation of this model was achieved by M'Pherson and Limantoro (1982) and Limantoro (1985). By using: (i) efficiency, (ii) quality and (iii) productivity measures through various aspects of the model compartments, such as: (i) money, (ii) energy, (iii) labour and (iv) technical process, measures for a national technology engine model were utilised. The total energy cost could then be used to give an accurate measure of technical work and efficiencies. The improvements in the efficiency and quality of the process were regarded as a result of a technical change by using this thermodynamic criteria which used economic and engineering resource data as inputs.

2.6 Stability Modelling in Technical Change

A general reflection on these models of technical change is that there is an implicit need to build some form of stability into their economic or engineering systems. This can be generated through an assumption of linear relations between elements, or through the reduction of information uncertainty within the process of technical change. These models which seek to utilise such apparatus are trying to construct some form of negative feedback, control (Ironmonger, 1983), or self-regulating mechanism (Vester, 1988), through economic criteria for the effective management of technical change. Laszlo (1986) identifies the problem using an approach from non-equilibrium systems theory, in that technical changes tend to generate widespread destabilising effects upon any social system. The argument follows that with increased technical efficiency there emerges a corresponding progression towards self-organisation within any form of natural system. The effect of new technology upon the social system is to increase their self organisation of the system through the development of intricate relations and the creation of flexible models using a high variety of intercommunications.

2.61 Negative Feedback in Modelling Technical Change

Robinson (1979) attempts to model technical change through an analysis of technical shifts. The simulation model known as 'TECH1' is an attempt to understand variations in the rate of technical substitution and how they might be controlled. The model describes the problems of technology shifts, in terms of competitive relations held between two production systems defined as: (i) old and (ii) new. That is, the technology is defined within the boundary of production capacities with differences being seen as variations in parameters of the production systems rather than in their different structures. The production system which uses the old technology (OT) values is shown in figure 2.5.

Indeed, the two production systems contain identical structures. They are seen as competitive in so far as the growth of one technology is assumed to preclude growth of the other. Competition between the two subsystems relies solely upon the product market rather than capital or labour inputs. The result is two technology models competing within a market sector model which is contained by a boundary of economic variables reflecting the production system. The competitive characteristics provide the information concerning how variations in rates of technical change occur. Controlling these rates of change is seen as an implicit function inherent within the modelling structure.

An analysis of this model identifies the basic causal feedback structure of a production system oriented to technology change. The structural description presents a possible sense of how the system might be controlled by modifying the cybernetic behaviour of the production system. This behaviour can be identified through the positive and

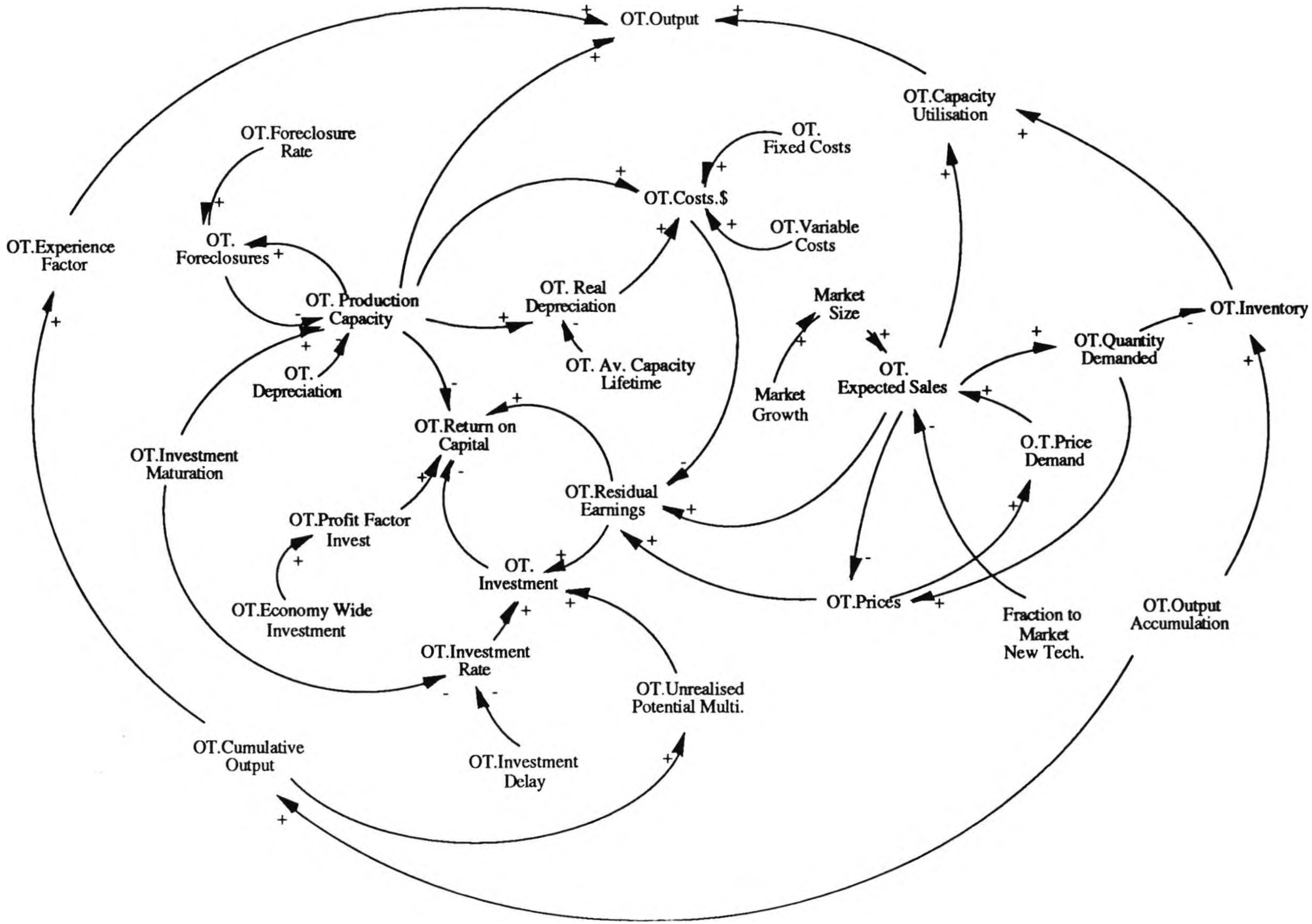


Figure 2.5 an interpretation of Robinson's (1979) model of techical characteristics within a production system

negative feedback mechanisms within the model structure. Positive feedback is the root cause of exponential growth or decay, and forms the mechanics which exaggerate the growth of the new technology. Yet the process of technical change is an irreversible one, and its stability is principally controlled through the identification of the behavioural aspects associated with the negative feedbacks in the production system.

Based upon the economics of production capacities, positive feedback operates primarily through the learning curve associated with the technology which acts upon both a short term (price and quantity demanded) and long term (price on market share and market share on sales) mechanisms. Because of the two technology sectors in the model, the learning curves are mutually exclusive and hence, illustrate a technical competitiveness. Robinson (1980) extends her description of the construction of the 'TECH1' model through an analysis of competition between product lines. In this description it is seen that the shape of the learning curves of both production efficiency and marketing efficiency are a powerful influence on the dynamics of the technical change and reflect an essential feature in the simulation model.

Laszlo (1986) assumes that the process of technical change is irreversible; that is once the transition from one technology to a new technology has occurred the process is unlikely to be reversed. The implication of such an assumption is that it stresses the importance of negative feedbacks within the Robinson (1980) model. The feedback mechanisms serve two fundamental functions: (i) to halt any potential technical decay in the system and (ii) to regulate the rate of changes in the technology.

This form of feedback is determined not from any internal mechanism, but from a stabilising link between the production systems and the market sector. Within the production systems, the negative feedback affects production capacity by weakening the capacity accelerator loop and regulates investment in technology through the feedback present on experience accumulation. In addition, the behaviour of these negative feedback functions are sensitive to the mathematical description and choice of theoretical assumptions. In the market sector the description of negative feedbacks are used to adjust demand and supply through price mechanisms. The long term effect of the influence of price mechanisms is to direct the market preference to the cheaper technology irrespective of the capability of the new technology compared to the old. In the short term, adjustments in quantity demanded are reflected either by the change in capacity from existing technology to new technology, or the description of influences on a capacity variable in the existing production system.

2.62 Restructuring in a Process of Technical Change

Zeigler and Reynolds (1985) introduce a model which explicitly considers a structural adaptation within the firm, to technical change through a problem solving system which occurs within a time-critical environment. The model itself is a suggestive rather than a definitive attempt for dealing with structural transformations by investigating the information processing environments surrounding the firm. This is a central feature of their approach which is based upon three features: (i) an opportunity rate, (ii) a response window and (iii) a problem type. For this analysis of technical change, the models' opportunity rate should be considered as synonymous with a technical change rate, assuming that the firm has the ability to capitalise on it.

What is unusual within this model is that, unlike the majority of models describing technical change, economic viability and productivity values do not play any explicit role in the model. However, they can be included implicitly through assumptions which support model interpretations. Technical change is given more of a descriptive role in the model, being presented as one particular consequence of a dynamic environment. The interpretation of technical change in this model is used to predict the structural characteristics and the trade off between flexibility and response times. The model assumes that when the performance curves of two competing technologies cross then, at that point, the firm will switch to the more superior performance curve, or risk the chance of technical obsolescence. This is characterised by changes in the structural conditions of the firm. Firms which operate in the same area of a given industry are assumed to receive the same opportunities, but that these firms differ in their ability to capitalise on them; that is only those able to respond adequately can do so. Therefore, the modelling interest focuses on the ability of an organisation to restructure itself such that adequate organisational response is achieved in the face of changing technologies.

The technical change is modelled primarily through the transfer mechanism which links the firms' internal construct to its environment. With a new function associated with technical development, the model is used to determine an optimal new structure. A check on each node (component) in the black box takes place in order to see whether a minor or major change is required. This is generated from new information within the environment. To determine the configuration of a new structure, two aspects have to be considered, (i) the throughput, that is the rate at which adaptation emerges from the structure, and (ii) the response time defined as the time taken to solve the technical problems. Within this structure, the fraction of the problem handled by each node is calculated along with the number of recursions derived from the total number of technical problems which has to be dealt with by the structure. Depending on the type of technical problem for the structure, different consequences are generated for each form of organisational structure. The result is that a trade off exists between structural flexibility and the response times.

If an opportunity, associated with new technology is envisaged, the model can deal with this as though it were illustrating a problem scenario. The requirement is then to generate a successful innovation which can become established within the organisation through a form of transfer mechanism, operating under a sustained input/output process, and performed by the system to capitalise on the technical opportunity. The firm is modelled so as to respond to the opportunity generated from information in the environment. When that innovation is established a change in the technology results with a subsequent change in the form of a transfer mechanism. Zeigler and Reynolds (1985) achieve a predictive model, insofar that it attempts to predict the structural hierarchy needed to cope with the emergence of new technical problems. In this manner, it attempts to link the structure of the 'black box' and technology characteristics to the firms operations. The idea is that the black box is constructed from a series of other interdependent black boxes which also exhibit recursive characteristics. The connection is created by directing information flows and synchronising the activities of the components of the black box.

The potential of this model appears to be dependent upon the mechanisms of control and communication, and how these characteristics might be used to introduce a form of structural stability based on the possible consequences of technical change derived from new technical problems. This model and the model included in Robinson (1979 and 1980), attempt to use such a mechanism, the former emphasises the decision framework used to model the process, the later using production principles whilst based on an economic foundation. Within this section there is another modelling format which relies on the need to present some type of stability mechanism in a process of technical change. These models are associated with the concept of self-organisation.

2.63 Self-Organisation in Economic Models of Technical Change

The theory of self-organisation deals with complex dynamical systems which develop through mutual co-evolution and undergo a number of successful structural transformations. Whilst modelling technical developments through economic agents of uncertainty, learning and disequilibrium dynamics, Silverberg, Dosi and Orsenigo

(1988) utilise the notion of self-organisation by using characteristics of: (i) technical variety, (ii) behavioural diversity and (iii) selection mechanisms, to illustrate how the spread of technical innovation occurs with its subsequent imitations, through a particular set of technical trajectories.

In Silverberg et al. (1988), technical evolution is governed by a series of equations which relate the rate of change of the firms market share to the difference between its competitiveness and the average industry competitiveness. The assumption made is that the competitive variable is synonymous with the process of innovation and technical change. Rather than describe the competition variable as a constant, Silverberg et al. (1988) treat it a a complex variable which links the factors concerned with the evolution of market share and average competitiveness within an industrial sector. Changes in relative competitiveness are then linked to the future course of embodied technical progress through an investment criteria. The model integrates other variables which are linked to the process of technical change. These include: (i) productive capacity, (ii) new capital equipment, (iii) scrapping dates, (iv) capacity expansion (contraction), (v) labour and (vi) production levels. To capture the dynamics of the process in this model, two technical trajectories are compared, each identical to one another apart from their productivity levels. These levels represent the degree of innovativeness of the technology. Technical efficiency is coordinated through a logistic experience curve, with the rate of change in this variable corresponding to the growth of cumulative production. Although the model describes dynamic behaviour, it also represents a degree of economic diversity and disequilibrium within the technical system, whilst the process of diffusion is illustrated as a stable structure. To this extent the model verifies the function of a sigmoid shaped diffusion pattern in general, although this does not always occur. The result of integrating these factors is the production of a decision making model which underscores the role of technical expectations, cumulativeness and strategic competitiveness.

This model extends beyond Robinson's (1980) model of competition. It profits from using an experience learning curve for each technical trajectory as well as learning about future expectations. The significance of this self-organisation model is not so much the application of self-organisation dynamics to economic theory, but that it attempts to model technical change drawn up from competitive equations derived from mathematical biology, particularly in the use of replicator dynamics to illustrate the governing force of market share.

Silverberg (1988) argues that the assumptions of self-organisation show that: (i) non-linearity, (ii) multiple equilibria, (iii) bifurcation and (iv) deterministic chaos are fundamental characteristics of technical change modelling. Once this is accepted, Silverberg (1988) debates the view expressed by the majority of equilibrium models of technical change. That is the process is one of technical adjustment or incrementalism, rather than one which deals with chance. But just as important, the theory of self-organisation focuses attention on the concept of the idea of the cooperative effects in many systems, and hence, can converge into a more structured and less differentiated state. In this area, Silverberg (1988) states that there are two possible modelling states: (i) where the model shows how the system moves between a small number of qualitatively distinct dynamic states, or (ii) illustrates the move from self-organisation to evolution. It is the use of the selection criteria which are mainly used as if technical change is modelled as an evolutionary phenomena. Yet a number of problems do exist in this type of modelling. Silverberg (1988) identifies two particular problematic areas.

2.631 The Unit of Selection

In biology the fundamental unit of selection has been recognised as *the gene*, but this is still unclear in terms of technical modelling, Silverberg (1988) questions whether this fundamental unit is the firm, the innovation or the technology. All of these units can be found in the literature, the problem is how to reconcile the differences each unit of selection introduces into the models.

2.632 The Role of Anticipation and Rationality

The philosopher, Jon Elster (Elster 1983), states that there are two main approaches to technical change. The first suggests that the process is conceived as rational and goal directed. The second suggests that it is a process of trial and error, accumulated through random modifications. A combination of approaches reveals a random but directed, or orthogenetic, (Silverberg, 1988) process of technical change. This revelation identifies that there is a behavioural level associated with the process, but in most economic models such behavioural aspects are relegated to an ad hoc position. Behaviour plays an important role in technical anticipation and in the selection of technologies. In this respect, defining the variables to illustrate such aspects is a problem for self-organisation models, but may be applied in a model through the introduction of decision rules.

2.64 The Limiting Powers of Evolution Models on Technical Changes

The evolutionary modelling approach to technical change claims that in some sense their models are more realistic or plausible than either ad hoc or behavioural approaches (Silverberg, 1988). Further, many of these models attempt to uncover long term patterns of technical change and economic development which is seen through the familiar sigmoid curve. Yet, one of the problems of this approach is that it hardly questions the relationship between the process of technical change and the disequilibrium it engenders with the short period instabilities and problems of effective economic demand.

For example, Nelson and Winter (1982, pp. 235-40) produce a model which uses linear production functions, and differs from the general evolution models only in respect to their labour productivities. All reinvestment enters the technology sectors and all output sells at a common price level. In summary the more productive technology gradually replaces the less productive and eventually the diffusion process approximates to the characteristic sigmoid shape. A number of other models, such as Gibbons and Metcalfe (1988) operate in the same manner. The results produced from the models reflect the argument that if output price changes are exogenous, the best technology will be adopted according to the demand of the industry, dependent on the capacity. In most instances the economic system which is being modelled can not do anything else, but converge on the new technology.

In these evolution models it is generally assumed that firms which adjust first will wait until the rest of the industry has converged onto this new technology, and this removes any potential for industrial disequilibrium. According to Silverberg (1988), this technical frontier does not remain stationary, and does not wait for the average firm to 'catch up' technically. In an attempt to diverge from this evolutionary tendency, Iwai (1984) presents a model which links technical selection with an advancing technical frontier. Although differential growth of technologies and unit costs are linked to the capacity of the firm and economic demand, technical change is expressed as a disembodied variable, and this highlights the ability of firms to jump from one technology to another without the requirement of technical investment.

A final example of the limitations to economic evolutionary models of technical change is that of the assumption that the difference in average unit costs are directly related to the use of different technical types. In this way an argument can be developed which shown that this assumption reflects the idea that technical changes can never be derived from strategic choices, but rather, from a consequence of a dissatisfaction with operating performance.

2.7 Conceptual Models: Additional Descriptions of Technical Change

General criticisms of economic modelling of technical change have developed from a strong reliance upon both capital and labour coefficients which have been largely based upon a neoclassical definition of the production function. Further characteristics which are identified with the economic evolutionary models of technical developments have already been cited as poor for their interpretation of technical changes. This may be assumed to be derived from the concentration on a means to generalise the process based on a production factor and hence, provides a limited power of explanation through production characteristics.

The space between rational and random technical change as described by Elster (1983) has largely been left to sociologists, pyschologists and anthropologists. Whilst many of the economic models not only utilise the basic foundations of neoclassical theory, but also elements of decision theory and game theory, the dominant sociological paradigm has been based on the human relations tradition (Brotherton, 1988). The models developed in these disciplines take on a different format, concentrating on: (i) rationality and intentionality of management and (ii) employee issues concerning technical change. It is largely based on the assumption that the dominant characteristic of technical change is behavioural. This behavioural absence in economic models has provided a niche in which disciplines such as occupational psychology have been able to develop strong conceptual models which link the behavioural aspects of work to the impact of technical changes. The implications are that these works have provided some additional descriptions of technical change which has been lacking in the majority of economic and engineering models.

2.71 The Cognitive Process in Models of Technical Change

Many of these 'human relation' models rely upon the assumption that technical changes are in fact a cognitive process. For example, the economist Joseph Schumpeter (1928) argued that a key element in the process of technical change was the attitude of the entrepreneur to new technical innovations. Models developed by: (i) Abraham and Haywood (1984), (ii) Robertson (1971), (iii) McFarlan, McKenny and Pyburn (1983) and (iv) Blackler and Brown (1986) follow very closely this endogenous character of technical change associated with the cognitive process. These associations being identified through the activities of research and development projects, rather than being exogenously determined through the economic impact of new technical developments.

The model developed by Abraham and Hayward (1984), investigates the complexities of introducing technical innovations into production systems at the industrial level. Rather than describe the process through a technical orientation, the model is used to describe the essential elements of technical change through known cognitive processes. The model is principally derived from Robertson's (1971) eight stage model of cognitive processes which is concerned with aspects of: (i) technical awareness, (ii) technical legitimisation, (iii) trials and (iv) adopting decisions. This produces a decision concerning the adoption of the new technology. However, it is the use of particular organisational structures, competitive aspects and decision making styles in the model which provides the main information source concerning perceptions of the process of technical change. This includes perceptions about: (i) research and development, (ii) manufacturing and (iii) the supplier.

A similar model of technical change which was developed by McFarlan et al. (1983) and extended by Raho, Blohlav, James and Fiedler (1987), also illustrates the process of cognition and learning. Furthermore, it reflects both internalised characteristics of new technology as well as environmental issues such as market dynamics and diffusion patterns, and there is a strong similarity to the three cognitive models developed by Blackler and Brown (1986). They give much more consideration to organisational and psychological issues to the firm and the environment rather than actual technical expressions derived from research and development activities. Blackler and Brown (1986) argue that all too often the change process is engineered around the tight control and coordination of technical and operational considerations, with the system design being used to reflect economic resourcing and machine capability. The models which Blackler and Brown (1986) emphasise still reflect the importance of economic considerations to the design of new technology but is based upon the principle of integrating social and psychological issues into technical changes such as: (i) work roles and (ii) staffing levels. It reflects a much more participative orientation.

The consequences of these models is the assumption that cognitive attitudes are an essential element in explaining how the process of technical change can be made viable within an organisational context. In general, there is a strong correspondence between introduction of new technology and the broader human relation descriptions of the firm.

2.72 Cultural Aspects in Modelling Technical Changes

Shrivastava and Souder (1987) present a model which illustrates that the elements of organisational culture do influence the nature of technical changes, with particular emphasis on the adoption of new technical innovations, as well as technical imitations. This characteristic of cultural influence on the nature of technical changes has also been operationalised by Elizur and Guttman (1976). The assumption is that, as with Zeigler and Reynold's (1985) conclusions, there can be no one optimal structure which can cope with technical changes. These cultural and climatic elements are viewed as an important aspect in defining technical problems, and this is coupled with the arguments presented by Rothwell and Wissema (1986), who state that culture is a determining force in perceived technical needs which can be translated through the diffusion of technical innovations. In addition to the characteristics associated with technical factors, such as: (i) competition, (ii) market share and (iii) production capacity, other cultural features defined through: (i) general political, (ii) social and (iii) legal factors have to be seen as essentially relevant to modelling the process of technical change.

2.8 Conclusions

To what extent is there a structural coherence between the models of technical change? Clearly, to the extent that no one model is currently being used to solve all the problems associated with technical change, there is an indication that structural coherence does not exist in the absolute sense. Nevertheless, there are a number of considerations which can be drawn from this review.

(i) The growth factor. The genealogical survey presented in this chapter and outlined in figure 2.6, illustrates the general course of developments in technical change models. The dominance of the production function model before the mid 1970's does suggest that a structural cohesion in the assumptions of technical change has existed. However, the explosion during the mid 1970's and the 1980's of a wide variety of technical change models generally rejected the continued use of the production function assumptions alone. Instead, alternative analytical investigations of technical change began which used particular structural assumptions regarding the nature of the process. These included assumptions about: (i) growth, (ii) competition, (iii) culture and in general, (iv) evolutionary considerations. Whilst this growth in models of technical change has, no doubt, benefited from further discussions on the nature of technical change, the loss has been in the unifying structural expression needed to analyse the implications of current thought on technical change.

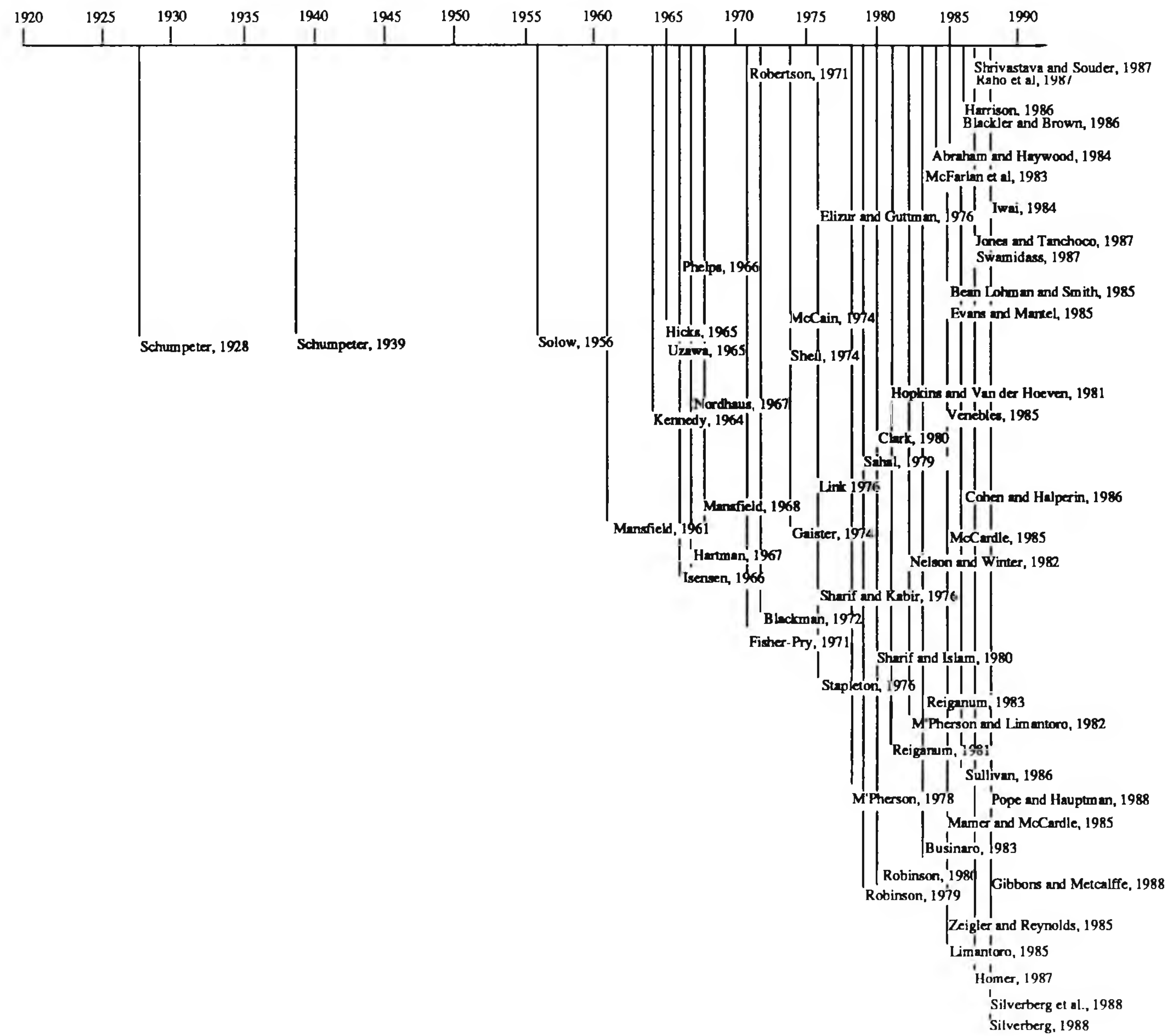


Figure 2.6 a genealogical presentation of technical change models identified in the review

(ii) An underlying trend. It has not been possible to determine a particular trend in which the more recent models have been developing. Rather the implication is that an increase in the diversity of the models is taking place. Much of this diversity occurs between the extreme assumptions of economic rationality on the one hand and a behaviourist interpretation of technical changes on the other. Whilst the conclusion from this observation is that this modelling diversity offers a expansion in understanding and explaining the implications of technical change, it occurs because there is a strong difference in the degree and manner of the structural assumptions.

(iii) General characteristics of technical change. Whilst this diversity has developed, there has also been a tendency to include in models some general characteristics associated with technical change. Despite their detailed structural differences, the aim of these models can be categorised in terms of a determinism to monitor, measure or simply explain such characteristics. In this sense a conclusion can be drawn that these characteristics are classified in three areas. These are: (i) technical uncertainty, (ii) technical stability and (iii) technical evolution.

The term 'technical uncertainty' is used in these concluding remarks as a means of expressing the 'unknown' consequences of technical change. By developing models which utilise the assumptions of Bayes' theorem, game theory or dynamical system theory, a reduction in the uncertainty associated with the events of technical competition, technical adoption and technical developments are established. Technical stability is used to refer to those homeostatic or homeorhetic characteristics within technical change models. Both selection and self-organisation models link negative feedback and positive feedback as sources of stability and instability in technical change. The characteristics of technical stability are used in these models to describe the means of removing states of temporary disequilibrium from the process, and inducing periods of stability. The characteristics of technical evolution are concerned with the diffusion and substitution effects of new technical improvements, and in addition, include aspects of cooperation, growth and adaptation which are incorporated into the evolution models of technical change. They present an approach which describes another general aspect of technical stability, and identified through a particular modelling approach which produces a state of technical equilibrium.

(iv) Model structures. There is no current consensus as to the general structure of technical change in the review of these models. This might only be achieved if there is a clear perception on the nature of technical change. These rely, for the present, simply on homomorphic associations concerning the nature of technical change with production, population growth and human cognition.

From these conclusions, the implications are that whilst there is an increasing number of technical change models which have been developed in recent years, the diversity in their approaches, structures and interpretations indicates conflicting impressions as to the nature of these changes. Whilst these models have incorporated some general characteristics, the possibility of deriving any synergistic information from them, by integrating their results, is not possible simply because of the different structural assumptions used. Establishing a coherent structure to technical change is an essential means in the coordination of technical change models. Existing model structures can be identified through their reliance on particular associations; but how do such associations determine the structure of these technical change models? And how can they provide the basis for a coherent structure of technical change? Chapter Three investigates these questions, and draws upon the mechanisms needed to establish a general structure for technical change models.

CHAPTER THREE

STRUCTURES OF TECHNICAL CHANGE

3.1 Introduction

Perhaps the most striking feature of the review presented in Chapter Two concerned the link between models of technical change and the use of economic and evolution characteristics defined in terms of: (i) production, (ii) price distribution, (iii) consumption of wealth, (iv) diffusion and (v) growth. This chapter examines how these associations determine a structure for technical change models and how a more comprehensive structural description can be sought through systems thinking.

This linkage of structural descriptions of technical change to growth and economic characteristics draws upon the influence of analogies. The first section of this chapter describes how the underlying and largely unexamined assumptions of analogy is currently to be considered the most suitable means of developing particular modelling structures of technical change. This is followed by a second section which examines the current analogical descriptions which dominate these technical change models. A detailed analysis of: (i) the evolution, (ii) production and (iii) other analogical variations. These are used to illustrate the existing structural base for technical change models, and leads to a debate concerning the very nature of technical change. In a third section, an account of the lack of dependence between these different analogical structures shows that new technical events which lie beyond these particular structures can introduce anomalies into the modelling explanations of future technical changes . The Chapter concludes with a description of how these problems limit any existing analogy as a means of developing a comprehensive framework for the structure of a new breed of technical change models.

3.2 An Introduction to Analogical Investigations

The concept of analogy has generally been used in science as a means to construct theories and models. It is traditionally recognised as part of an inductive scientific process, that is if the analogy appeared to represent a possible form of scientific mechanism (Agassi, 1964). There are various aspects to analogical investigations, these being: (i) analogical thinking, (ii) analogical problem solving, (iii) learning by analogy and (iv) analogical reasoning. The development of analogy has seen the rise of two particular forms, that of the syntactic and the pragmatic perspective (Keane, 1988). These two forms, have tended to develop in opposition. Although these differences are not the primary focus of this chapter, both approaches provide some insight into the mechanisms for any analogical investigation, and are applicable to this discussion.

Keane (1988) discusses Winston's (1980) analogical theory, which he describes as being concerned with the issue of how one can match two domains of knowledge, and how the possible explosion of matches can be considered in order to make a good analogy. For Winston (1982) it is not necessary to consider all the parts of a situation as equally important, rather it is possible to determine what is important by paying attention to the constraints in the base domain, that is to the limitations in the 'familiar' situation. This usually means identifying any causal relations, rather than the elements which might belong to the domain. The implication is that:

> " Thus, in comparing the plot of Romeo and Juliet with Cinderella, the matcher first established that Romeo and the Prince were male and Juliet and Cinderella female."
>
> (Keane, 1988, p. 233)

But there are problems with building an analogy through the development of causal relations: For example, if it is assumed that Mrs Bush is the first lady of the US, and if a question was asked, who is the first lady of Britain ? It is quite sensible to reply (with a grin) 'Dennis Thatcher' (Keane, 1988).

Keane (1988) correctly states that any analogical investigation is more than just matching two different domains. This is merely the prelude. The essence of analogical investigation is to form particular inferences in the target domain, that is the situation which is 'unfamiliar', which can significantly enhance one's knowledge of that domain. For Gentner (1983) the most important aspect is the generation of mapping rules. These allow for relations to match other relations and attributes to match other attributes. Such a process of analogical investigation often provides the mechanism for an alternative form of representation, it also illustrates certain invariants between two sources, and which are defined by Keane (1988) as the degree of systemacity. Yet whilst analogies and generalisations may illustrate varying degrees of similarity, Agassi (1964) states that the viability of any analogy stems from the fruitfulness in suggesting a possible theoretical base or an extension of it. Moreover if the properties and objects of one source can be derived from similar properties and objects of another source then, according to Agassi (1964), a 'proper' analogy exists rather than an 'ad hoc' analogy which may illustrate only some degree of similarity, but in no way can provide a theoretical base. In this sense the 'ad hoc' analogy can be regarded as superficial to the investigations.

These concepts of causal relations and systemacity are expressed algebraically by Sierocki and Tchon (1982) who argue that if it is assumed that Σ defines a class of system ($\emptyset$), such that: $\emptyset, \emptyset' \in \Sigma$, a relation of similarity holds if $\emptyset, \emptyset' \in R$. From this evidence, if $\emptyset \in P$ then assuming the relation of similarity holds it can be reasoned by analogy that, $\emptyset' \in P$ without any direct reference to $\emptyset'$. In Winston's (1980) theory, Σ represents the nature of causal relations, whilst for Gentner (1983) the degree of systemacity holds in the identity of the variable R.

This degree of systemacity represents one of the most important concepts associated with analogical investigations. This concept is primarily concerned with the applicability of the relationship between the base or 'familiar' domain and the target or 'unfamiliar' domain. Sierocki and Tchon (1982) define this causal relation in terms of whether it exhibits one of three different characteristics, according to the degree of: (i) equivalence, (ii) similarity or (iii) weakness. The systemacity can be expressed in these terms, with the result that it provides an analogical basis which can be interpreted in terms of structural and behavioural similarity. This important concept is extended by Flood and Robinson (1988a) who argue that it is not just systemacity which is important in the derivation of an appropriate analogical model, but that the characteristics of dissimilarity can also highlight the limitation of any proposed model which may subsequently develop from the analogical investigation.

The basis for any particular analogy is defined through this process of analogical investigation, with Flood and Robinson (1988b) arguing that in the context of analogy, a two way relationship must be held valid between an analogy and a model if any theoretical base is to be developed or extended. This was first advocated by Achinstein (1964), who stressed the importance of models and analogies in the understanding and development of scientific theories. Whilst Achinstein (1964) tends to use the concept of analogy and model interchangeably, he specifies that an analogy is characterised as a structural comparison which is drawn between certain objects. A model is developed to correspond to a set of assumptions describing certain objects. As such, it is possible to agree with the arguments proposed by Girill (1971) that analogy and model can be distinct up to a point, with the distinction blurring when an attempt is made to use a model only in an analogical context. This is particularly so, in the context of using models of biological growth as analogies for the interpretation of technical growth. The biological growth model can be used in Winston's (1980) analogical theory, because it identifies causal relations between the characteristics of biological growth and those of technical growth. Further, the model is used because it expresses the systemacity. According to Gentner (1983), this is found in the set of assumptions describing certain objects which can be transferred to the other domain, that is the model actually moves into the analogical context. With this is mind, one has to make the assumption that the relationship between analogy and model is complementary rather than competitive.

According to Flood and Robinson (1988b) the derivation of a new model from an analogical description requires three aspects: (i) a theory, (ii) an analogue set and (iii) a new domain. This then extends the purpose of analogical investigation identified by Carloyle (1971), from the functions of revision, reinterpretation, mediation and theory extension, to that where the key problem is identifying the basis for an inference through the principles of analogical mapping. For Gentner (1983), such mapping requires certain rules. Keane (1988) identifies them as: (i) the removal of attributes from objects, (ii) relations between objects in the base domain to be mapped across to the target domain and (iii) the relations mapped determine the existence of higher order constraining relations. These rules link between the three aspects outlined by Flood and Robinson (1988b) and provide a consistent means of pairing different domains in an analogical investigation.

For Achinstein (1964), if a theory in the base domain can be compared with another object or target domain, the comparison can only be made in a limited number of respects. For example, when an analogy is drawn between an atom and the solar system, only certain properties of the atoms and the solar system are relevant to the analogical description. The relations which are not analogically related are explained by Gentner's (1983) rules. If a relation is not mapped onto the target domain it is because it is not systematically interconnected to the other relations in the base domain. According to Achinstein's (1964) analogical investigation, this includes the properties attributed to atoms by the Bohr theory, such as quantum jumps and electromagnetic radiation. These properties in the Bohr theory can be in no way considered relevant to the solar system as they lack the systemacity for the solitary reason that these relational properties can not be found. Only certain relational properties are therefore relevant, such as those aspects concerning rotation, relative weights and relative position. Keane (1988) argues that the goodness of the match is determined by the extent to which items involved in it are connected to other items in the respective domain. Hence the idea of systemacity plays an important role in the construction of the analogy. The role of these pairings is such that the viability of the analogy results from the construction of numerous matches between the base and target domain, that is, the more the inferences, the greater the acceptability. The implication is that, a good analogical mapping from the base domain to the target domain may provide new inferences regarding attributes associated with the causal relations, this is shown in figure 3.1. For example, associated with the analogical relation of relative weight between the atom and the solar system, it is possible to state that weight difference between the electron and the nucleus will cause it to orbit around the nucleus. This can then be analogically linked to the orbit of planets around the sun in the solar system.

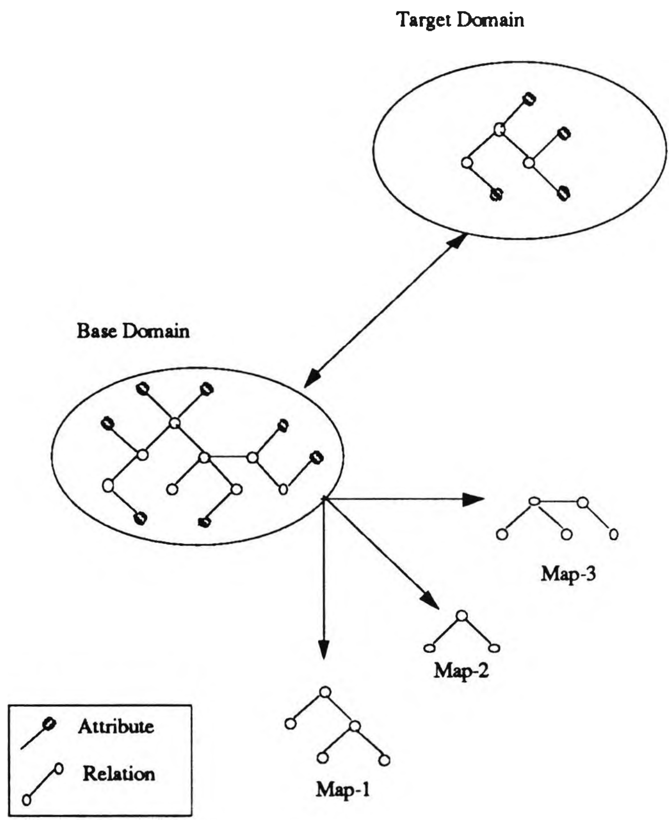


Figure 3.1 possible relational structures derived from the base domain for mapping to the target domain (Keane, 1988, p. 236)

This usefulness of analogy, as cited by Agassi (1964), is for the provision of the appropriate mechanisms for reinterpretation, such as: (i) generating the basis for inference about new facts, (ii) mediation and (iii) the extension of theory. This provides some insight into the wide variety of analogical functions and the validity of the approach adopted. In particular, Flood and Robinson (1988b) argue that analogy behaves as a mediation language between a base and target domain. Such mediation allows for the identification of properties which can be transferred across different domains, as identified in the previous example. But the validity of determining whether the mapping which is carried over to the target domain is appropriate, can only be judged on evaluation. According to Keane (1988) validity is typically left aside until the mapping process is complete, but this can often lead to a set of mappings which are meaningless in the target domain. In this respect the process must include a mechanism for viability. If it does not the analogy can only be seen as providing an improper basis for analogical inference. Flood and Robinson (1989) also raise this point, stating that it is essential to consider the sense in which the inference that is used by the analogy has a particular grounding, and more specifically whether the use of the analogy has taken place in a groundless process. One of the key features of this problem of validity concerns the identity of causal relations, that is the notion of similarity between different domains.

This can be interpreted by questioning the basis of the analogy such that, not only does one question whether there is a relationship between production characteristics and technical change, but whether there is any use in providing such an analogical statement. This is reflected in Limantoro's (1985) work, in which he describes the 'striking' similarity between biological growth and technical change as:

> " Regardless of whether the use of growth curves is acceptable as a refined form of analogy, or simply as a workable tool without regard to possible analogy, it is still necessary to project the curve beyond existing historical data."
>
> (Limantoro, 1985, p. 21)

This type of questioning highlights the usefulness of analogical modelling, such that Flood and Robinson (1989) propose a degree of usefulness along a continuum, ranging from the formal analogical model to the romantic metaphor proposed by Atkinson (1984) which provides an informed insight in an unfamiliar situation. The continuum highlights the importance of the analogical relation, R defined algebraically through $\emptyset, \emptyset' \in R$.

It is at this point that the use of analogy in the context of technical change is introduced. The aim, for the moment is to present a clear and detailed account of the usefulness and limitations of current analogical structures with respect to the target domain of technical change in this area of scientific enquiry.

3.3 Introducing Analogies in Technical Change Models

The argument developed in the preceding section has been used to elicit the fundamental reasoning behind the use and applicability of analogies to scientific enquiry in general. The intention is now to turn this to the applicability of analogical investigations to technical change. This necessity derives from an inability to provide a functional interpretation of the structure of technical change, directly. If an explanatory attempt is made, at best, the explanation of technical change appears to be understood only in the context of actual changes in the technology (Sahal, 1979a). As a result, the use of analogy is frequently treated, in this context, as a mechanism which provides an opportunity to structure the process in parallel with an alternative domain, which appears at least comparable. This idea of comparability through analogy also provides a view of how the general behaviour of technical change can be explained. The potential of analogy is that it can offer a means of explaining characteristics of technical change, such as: (i) growth, (ii) diffusion and (iii) substitution processes, through a relational similarity between a base and the target domain. The implication here is that an exploration of the causal patterns and attributes in the base domain can provide a representative description for the target domain through the mediation properties of the analogy.

This discussion will be used as a characterisation or outline, for the identification and illustration of the most notable analogies used in modelling technical change. It will be accomplished by integrating, modifying and extending existing material derived from the models of technical change and by providing a synthesis which discusses the evolution of analogical use in this particular target domain. This significant contribution identifies that the use of various analogies provides an ability to generate and preserve a number of appropriate structural frameworks for understanding technical change. This analysis learns from past analogical use in order to identify possible anomalies and mistakes from the basis of familiar structures. This approach corresponds closely with the following statement:

> " We cannot learn to be surprised or astonished at something unless we have a view of how it ought to be; and that view is almost certainly an analogy. We cannot learn that we have made a mistake unless we can make a mistake; and our mistake is almost always in the form of an analogy to some other piece of experience."
>
> (Oppenheimer, 1956, pp. 128-129)

The initial link between analogy and technical change is identified by two primary themes. These themes are concerned with the evolutionary nature of technical change and the economic consequences of such changes. To determine the potential of existing analogical contributions to modelling descriptions of technical change, the following discussion analyses the fundamental aspects of analogical interpretation with regard to the structural similarities between technical change and the base domains in these themes of economics and evolution. The investigation initially focuses on the similarities between population growth/dynamics, and that of technical developments.

Secondly, the link between economics and a production analogy is examined. This describes the similarity between changes in production characteristics, price distributions and wage changes to that of technical change. Although the usefulness of analogy is identified, a description of how these resemble and differ from the functional understanding of technical change is also given. This is primarily derived from an identification of the limit of causal patterns and dissimilar attributes between the analogy and the target domain. This gives rise to the discovery of the appropriateness of particular analogies as potential catalysts for creative thought concerning the target domain of technical change.

3.31 The Evolution Analogy

The use of biological expressions when dealing with technology in general, are not uncommon. Often such expressions are employed to highlight the major characteristics of change through identification of parallels between the concepts of evolution and technical changes. Businaro (1983) provides an extensive and interesting paper on the application of the ideas of evolution to the characteristics of technical development. His analysis does indicate that the concept of analogy and metaphor are interchangeable, to the extent that the metaphor which is offered and described is used, not in the 'romantic' sense as illustrated by Flood and Robinson (1988b), but as an analogical means of constructing a model of technical change. This evolution analogy consists of a two stage process of mutation and selection and reveals that a striking parallel between the two domains of evolution and technical development does indeed exist. This simplistic analogy conceals possible conflictual mapping relations within the base domain and is highlighted by the different aspects which are emphasised by the various perspectives held by, for example microbiologists and palaeontologists. The result is an analogical conflict within the base domain such that any translation of the analogy does depend on the nature of the understanding and explanation which is attached. It is particularly within this area of conflict (in the base domain) that disagreements arise concerning the applicability of transferring base domain assumptions to any new domain. Often the nature of the analogy comes into question before the translation has occurred (Businaro, 1983). For example, a palaentologist would emphasise the finality of evolution, implying in the analogical sense that technology has some ultimate final position, yet the microbiologist would imply that technical development can be analysed as either a 'chance' event or consistent with the idea of 'survival of the fittest' depending on the assumptions of the evolution.

Businaro's (1983) account of the evolutionary analogy consists of four main characteristics, classified in terms of the technical domain. Thcsc are: (i) a process for generating ideas, (ii) a container for accumulated inventions, (iii) a connection between invention and selection and (iv) a selection machine. The parallels between this and a general evolutionary domain are illustrated in figure 3.2. Drawing upon similarities, this analogy illustrates the potential of a description of technical change through evolutionary characteristics. The applicability of the analogy rests in Businaro's (1983) terms, with the particular structural characteristics, such as: (i) the storage facility and (ii) the valve mechanisms presented by the analogy. These appear to represent the most interesting features that dominate the the idea of a preferred technical path as well as the aspects of different speed of development, times and conditions of the process.

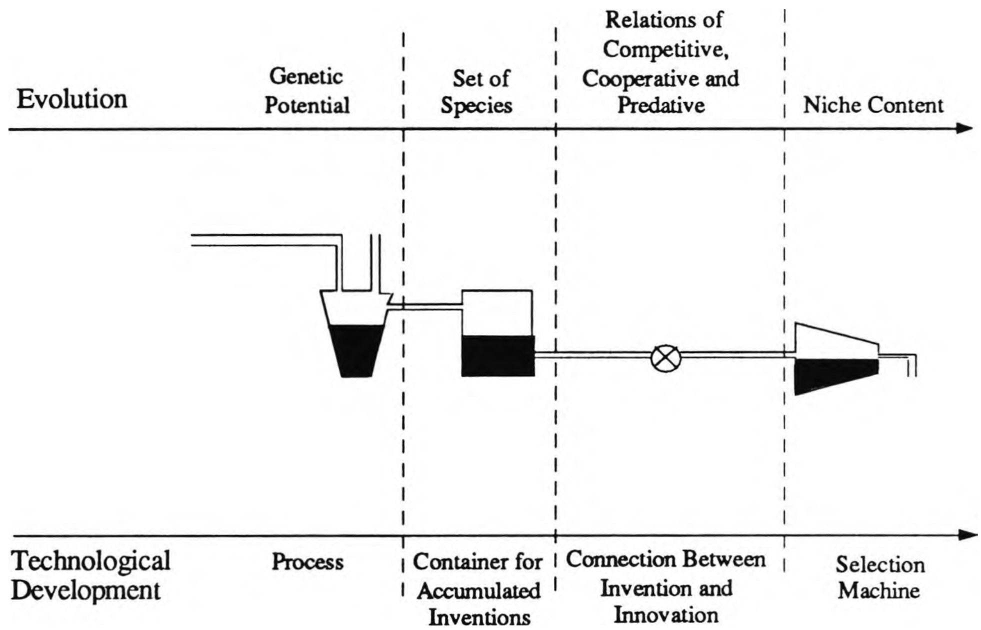


Figure 3.2 an interpretation of Businaro's (1983) analogical link between evolution and technical development.

However, these favourable comparisons, as in the selection processes, are very often overshadowed by the analogical dissimilarities. Whether this is by taking the analogy beyond its 'natural' limit, or by finding that the analogy is more superficial than was originally imagined, these dissimilarities or anomalies identify the apparent inconsistencies in analogy usage. For Businaro (1983) the evolutionary analogy contains certain inconsistencies which can not explain, or model, the impact of catastrophic changes in the target domain, such as the appearance of a new technical specification (or speciation). The resulting indication is that the evolutionary analogy does help provide a structural framework for modelling the 'anagenesis' of technical change, that is continuous evolution. However, the structure appears to break down if there is a sudden change or 'cladegenesis' of technology. The evolution analogy provides dissimilar characteristics in this area to the target domain. The argument is such that cladegenesis, may be explained in the base domain as pertaining to isolation of the environment, transplanting existing species into a new environment or hybridization among close species. Although these are explanatory within the base domain, the causal patterns which provide the mapping ability of the analogy require a new form of evolutionary analogy, one that incorporates the traditional anagenetic events, but also those technical cladegenetic events.

The foregoing discussion has already provided certain 'hints' on how a general evolution analogy can provide a modelling structure which helps to explain changes in technical developments. A more detailed analysis of the evolutionary analogy is presented below which describes the potential and the possible limits of this analogy. A distinction is clearly identified which separates the evolutionary analogy between aspects of Darwinism and 'survival of the fittest' to the palaentologistic idea that evolutionary development is bounded by some finite and constraining value. These two divergent characteristics are described by an analysis of biological growth dynamics which illustrate the bounded nature of technical development, and the biological reproduction analogy used to describe 'Darwinistic' associations with new technology.

3.311 Biological Growth Analogies

Generally, the use of a growth analogy to map characteristics, which help to explain the domain of technical change, has been used to provide structural parallels with the familiar set of organism development. This has dominated many modelling perspectives which have the main intention of predicting or forecasting potential technical improvements. These analogies of biological growth have generally been used to illustrate the growth in performance of technical devices. The use of the analogy has generally been to illustrate the similarity between the dynamics of technical development with that of the dynamics involved in the biological growth of organisms. But the limit of this analogy is identified by Boulding (1956) in so far that:

> "There is hardly a science in which the growth phenomenon does not have some importance, and although there may be a great difference in complexity between the growth of crystals, embryos and societies, many of the principles and concepts which are important at the lower levels are also illuminating at higher levels. Some growth phenomenon can be dealt with in terms of relatively simple population models, the solution of which yields growth curves of single variables. At the more complex levels structural problems become dominant and the complex interrelationships between growth and form are the focus of interest."
>
> Boulding (1956, p. 13)

All biological growth analogies are represented by a simple formula, in the shape of a logistic curve, which is mapped onto the target domain of technical change. The main reason for using such a logistic curve, according to Limantoro (1985), is that the growth curve can be considered as a refined form of evolutionary analogy which presents a simple and workable mechanism, and provides the means to project the curve beyond existing technologically historical data. The result, as stated by Boulding (1956), is the emergence of a description of technical change through a single variable.

An Illustration

The first biological growth model was developed by Pearl (1925) which described a model of biological growth according to the function [1]:

$$y = \frac{L}{1+ a.\exp(-bt)} \qquad [1]$$

where L characterises the limiting value of growth which was related to the time period t and constants a and b. A graphical illustration is given in figure 3.3. Accepting that a clear similarity between the historical data and the biological logistic growth curve exists, as identified in figure 3.4 then this provides a form of analogical acceptance. This provides a basis upon which the analogy can be subsequently used to describe three main characteristics of technical change.

From the graphical description provided by the analogy of biological growth, they include: (i) identifying the time period from idea to invention that is, the lag phase, (ii) the projecting of technical maturity, that is the determination of the logarithmic phase and (iii) identifying the rate of change of the technology itself.

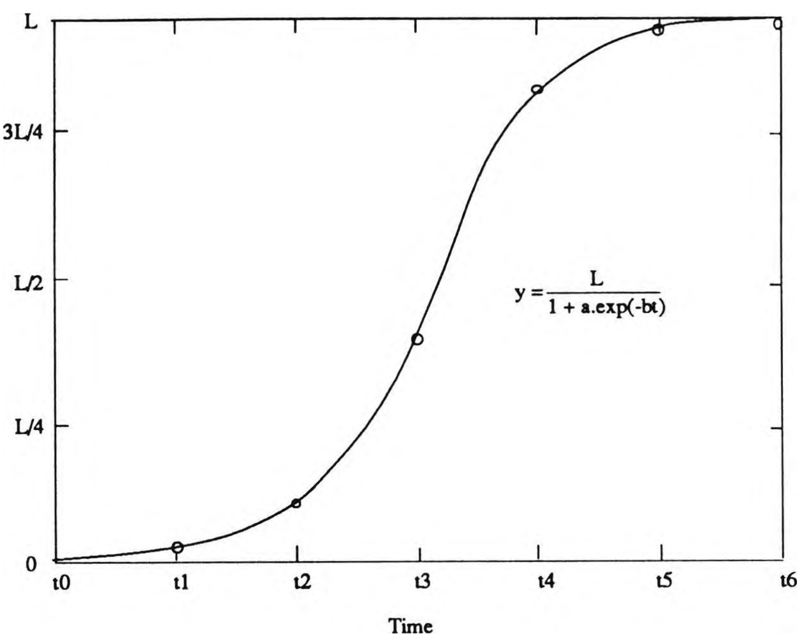


Figure 3.3 the growth curve of new technology

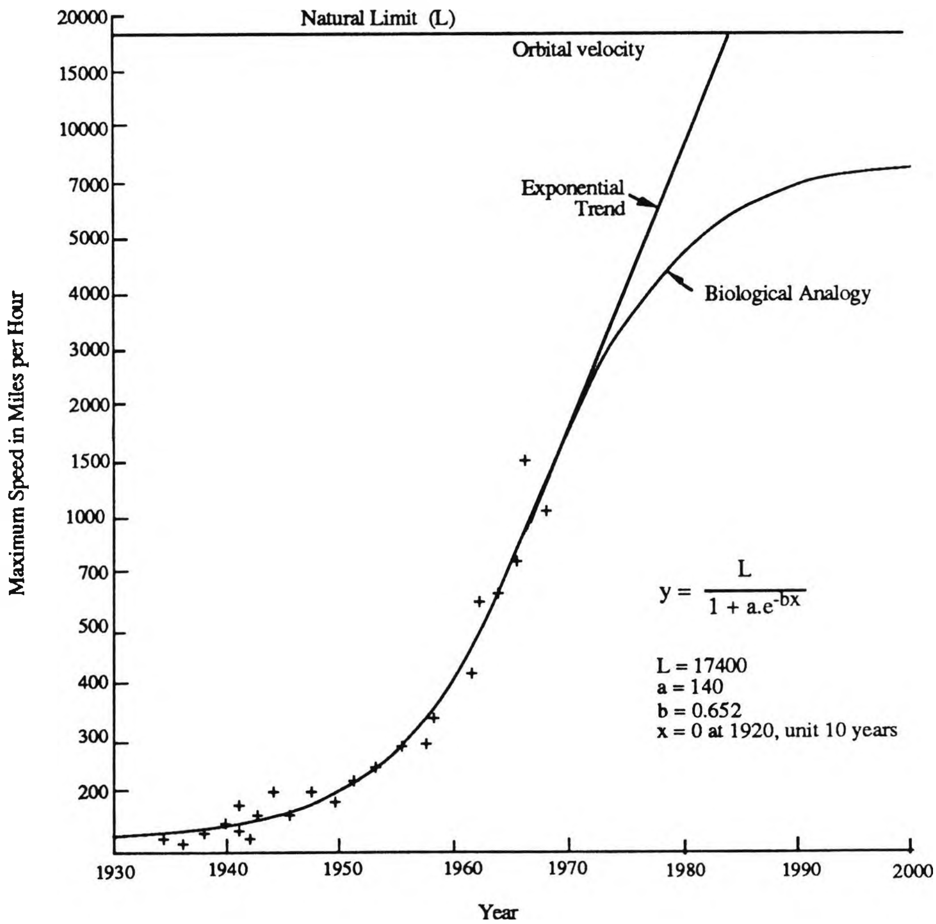


Figure 3.4 the link between historical speed trend data in U.S aircraft technology and the logistic growth curve (Lanford, 1972, p. 80)

These characteristics are seen as the main factors in any descriptive and explanatory model concerned with the process of technical change. The case which favours such assumptions argues that a single variable technology can be coupled with these modelling characteristics to provide a strong basis for identification of potential technical changes. Although the analogy does not go so far as to explicitly include the Darwinian notions of mutation and selection (Businaro, 1983), this analogy assumes that an ultimate value of technology can be reached. This is identified in the Pearl (1925) equation by the limiting value, L. Clearly, some important and yet simple parallels do exist with these assumptions.

Boulding (1956) identifies growth as one of the universal experiences, and an essential aspect of behaviour. Growth phenomena can generally be dealt with by most simple population models and he argues, that the concept of growth may indeed provide a comprehensive general theory. However, an understanding of the complex nature of technical change can be derived from a more detailed analogical study. The following passage provides an example by describing the analogical relationship between cell kinetics and technical change.

3.312 Using a Cellular Growth Analogy

The subject of cell kinetics embraces the temporal evolution of cell populations in terms of generation times, age distribution etc. Lenz (1962) introduces the concept of cell kinetics, and in particular cellular growth, as a potentially useful analogy which corresponds to similar characteristics in technical developments.

Cell kinetics is primarily concerned with information related to the dynamic growth of cells. In these cell kinetic analyses, the main assumption is that cells grown through a batch culture are contained in an environment of finite extent. This is such that the nutrient media of the cell, such as oxygen, is eventually depleted. The effect of oxygen depletion, creates a crowding condition, which when established, generates unacceptable levels of toxins in the nutrient media. The effect is a population (n) growth of cells according to the function [2]:

$$n = \frac{n_0 . N}{n_0 + (N - n_0)\exp(-\gamma t)} \qquad [2]$$

Where N reflects the stable equilibrium value and γ the fractional growth rate of the cells. Experimental research led to the formation of the growth law. The observations of Gause (1934) of the growth of *Paramecium caudatum* in a nutrient media of fixed volume led to the graph in figure 3.5.

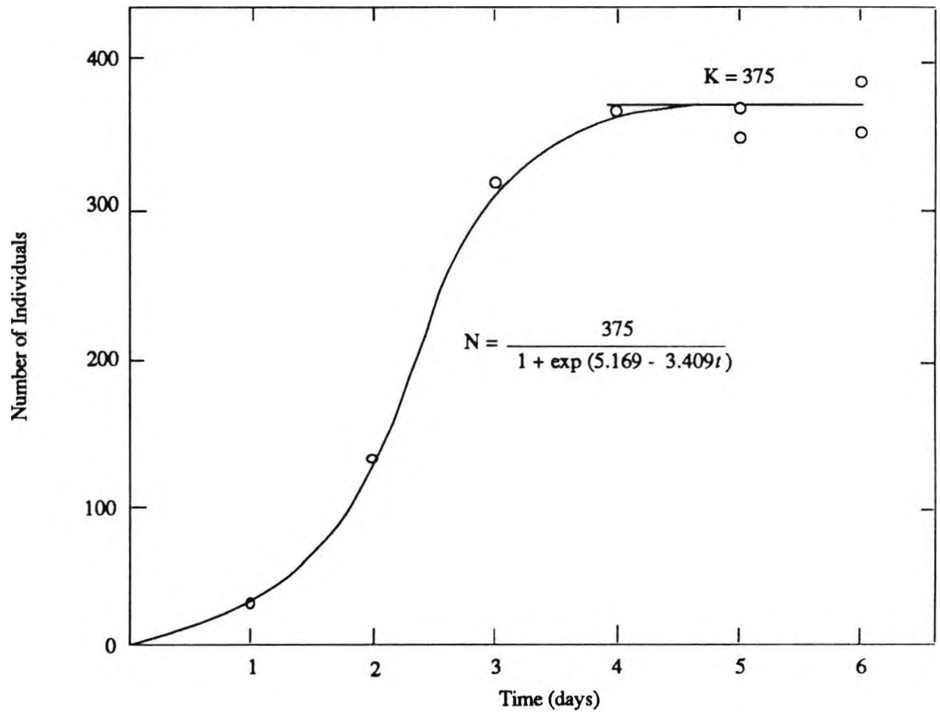


Figure 3.5 data representing the growth of *Paramecium Caudatum* in nutrient media of fixed volume fitted with the logistic growth curve (Segel, 1980, p. 503)

In cell kinetics, Segel (1980) states that a useful parameter in the analysis of cellular growth, is the doubling time of a population or the mean generation times such as the cell division period. In single cell micro-organisms such attributes are invariant, yet based on the data of Prescott (1959) the illustration in figure 3.6 highlights the time distribution function of the protozoan *tetrahymena geleii*..

According to Lenz (1962) such characteristics of cellular growth are also present in any analysis of technical development. By using this understanding of cellular growth in the analogical context to technical change, it is possible to represent these growth characteristics in the target domain. For example, the initial idea or invention should be considered as if it contained dynamic attributes similar to that of the initial cell in the cellular growth analogy. The nutrient media can be considered to as the economic support for the new invention, that is, the oxygen for technical development. Further, explanations of the time required to initiate new inventions, can be placed into the

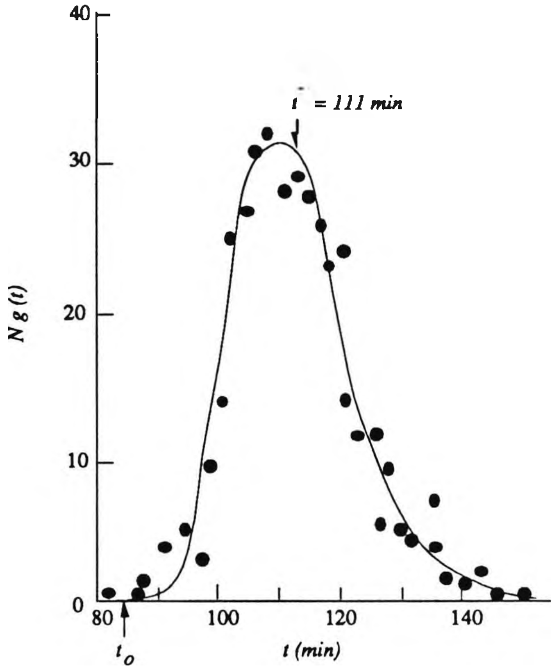


Figure 3.6 division time of cells for *Tetrahymena Geleii* (Segel, 1980, p. 506)

context of the analogical characteristic of the cell division period, with the cell division being considered as the process of invention and the second generation cell as the new idea or invention. The usefulness of such an analogy is that it presents a theoretical starting point from which data concerned with technical developments can be described. The use of the analogy presents new characteristics based on graphical and mathematical grounds by which technical development can be analysed.

This analogy can be extended. The period of time between the birth of a cell and its disappearance as a result of a cell division is referred to as the cell cycle, or cell lifetime, and portrays particular characteristics over a series of phases. If this reasoning is mapped, in an analogical context, then these features appear similar to the useful life of an invention, which derives particular characteristics within each stage of development. The result is the determination of the technical obsolescence of the invention, or product life cycle, which can also be described through the analogy through the characteristic of cell death.

The maturity of the cells is an essential characteristic in understanding cell kinetics, and gives rise to added analogical features in regard to technical development. For example, the maturity of the cells is dependent upon cell division and the total size of the cell population. The result is the following equation [3]:

$$N_{(t)} = \int_{\mu_0}^{\mu_1} n(\mu,t)\, d\mu . \qquad [3]$$

where μ_x reflects the maturation state at the phase positions, and the total cell population as $N_{(t)}$. By continuing to consider this equation in the analogical context introduces the importance of technical maturation with respect to the number of technical ideas. Yet, maturation in the cellular context in measured in terms of cellular volume or cellular content. This also corresponds to technical features such that maturation states of technical development are dependent upon the economic demand for the invention in a given technical area, and the total size of the technical area.

The example below identifies a striking resemblance between the movement of cellular populations with the movement of technology towards new locations. The analogical characteristic in this case, is population chemotaxis, which occurs when an organism moves preferentially toward a relatively high concentration of some chemical or away from a relatively low concentration chemical (Segel, 1980). The causal link can be found in the hypothesis that technical movement operates in a similar manner within the technical domain. Movements such as these can be seen to be dependent on certain economic criteria such as: (i) profitability potentials and (ii) economic growth rates. For this target domain, it is assumed that such characteristics represent a form of economic 'chemical' activity which motivates the movement of technology, that is technical change.

This example illustrates certain characteristics which are apparent in using the analogy to describe technical movements. A full account of the activity of cellular population chemotaxis can be found in Segel (1980, pp. 486-501). The consequence of this analogy is that the target domain of technical change can be constructed from a series of equations which highlight certain characteristics for technical change. Total amount of technical changes (T) can be defined as a combination of random and chemotaxic movements.

$$T = T_{\text{random}} + T_{\text{chemotaxic}} \qquad [4]$$

The rate of technical movement can be considered as $-\frac{dT}{dx}$, where x denotes a single coordinate in a technical area. The rate of change of technology can be given by:

$$\frac{dT}{dt} = Q - \frac{dT}{dx}. \qquad [5]$$

where Q, is the difference between technical birth and death rates. If it is assumed that economic profitability (p) is the technical attractor, then the technical chemotaxis can be defined by the following function, where a technical sensitivity function (S) operates and, where the value, a, is defined as the technical density, that is the amount of technology in any given area:

$$T_{chemotaxic} = S.a.\frac{dp}{dx} \qquad [6]$$

Random technical movements are defined by a mobility coefficient and the rate of change of density to the change in the spatial coordinate, thus:

$$T_{random} = - \mu . \frac{dp}{dx} \qquad [7]$$

The fundamental equation which illustrates the process of technical change through this analogical orientation is given by [6] and [7] into [5]:

$$\frac{dT}{dt} = Q - \frac{d}{dx}\left[- \mu .(p). \frac{dp}{dx} + S .(p).a. \frac{dp}{dx}\right] \qquad [8]$$

According to Segel (1980) an instability mechanism operates in this area which, in terms of the domain of technical change, reflects the rate of change of the economic profitability. This is built up from the potential profitability of the technology (a secretion mechanism, f_a), an obsolescence factor (-kp) and a diffusion coefficient (D). The equation [9] illustrates the rate of change of profitability in a particular location:

$$\frac{dp}{dt} = f_a - kp + D\frac{d^2p}{dx^2} \qquad [9]$$

Observations on biological population chemotaxis have found that the chemotaxic sensitivity of amoeba and the secretion rate of the chemical both increase before the onset of aggregation in a particular area, (Segel, 1980). By assuming that such characteristics are transferable to the domain of technical change, and coupled with the equations which have been developed, it is possible to draw tentative conclusions concerning the structure of technical changes within a limited time span.

The results of analysing possible technical chemotaxic activity through this analogy are given as: (i) stable technical changes can occur when there are slow parameter changes in the technical sensitivity function (S) and the secretion mechanism, (f), but only if the values are greater than the random mobility coefficient (μ) and the diffusion coefficient (D). (ii) Unstable technical change can occur if an effective change in the obsolescence factor (k) occurs. (iii) Dominant technical changes will commence later in smaller location areas.

Although the benefit of analogical investigation lies in the ability to provide explanations concerning unfamiliar characteristics in the target domain, the limitations of such analogical examples lie in the area of verification. As base domain equations emerge, validation of such general structural patterns can be provided by data concerning biological population chemotaxic activity. By transferring such characteristics to a new domain, it is necessary to utilise available target domain data to justify the assumptions. For the technical change domain, possible areas of concern can be seen in the non-uniform character of technologies, in terms of technical variability. Random aspects concerning technical changes are very often the consequence of other economic, engineering criteria which can not be included in the chemotaxic equations.

3.331 The Mutation and Selection Analogies

This section focuses particular attention on the use of the characteristics of reproduction as an analogical mechanism for structuring technical change. This alternative evolutionary analogy discusses the importance of mutation and selection properties within the target domain. Changes in population content describe the fundamental causal relationship between the base and target domain in this analysis. As with growth dynamics, the applicability of this analogy can cut across many different disciplines. As a consequence, different interpretations of the base domain provide alternative means for analogical investigations. The previous example described how the dynamic property of population growth can analogously represent technical changes resulting in a finite technical equilibrium. However, change in the analogical interpretation does not derive from a change in the causal relations within the base domain, but a different explanation of the attributes associated with those relations. The effect for example, would be to re-examine the Pearl (1925) model using 'Darwinian' assumptions concerning the evolutionary aspects of mutation and selection. The result would identify a different set of explanatory characteristics for the target domain of technical change.

The Illustration Re-examined

According to Sutton and Harmon (1973) it is the specific combinatorial process of mutation and selection which provides for the evolution of any biological species. Evolution derives from the interaction of differing genetic material together with the influence of outside forces to generate specific changes through mutation and selection mechanisms. By taking these assumptions, it is possible to re-examine the biological growth model proposed by Pearl (1925) in equation [10].

$$y = \frac{L}{1+ a.\exp(-bt)} \qquad [10]$$

The concept of mutation can be assumed in this characteristic biological growth model, described above, and is identified by the combined variables (a.exp.(-bt)). This formula can be interpreted to refer to the ability of a population to increase in size, based on the changes in environmental pressure and the adaptive traits of the species. Further, the difference between the actual size of a population and its finite limit, provides for an appropriate mechanism to select any further changes to the population growth rate.

Thus, if the analogy is mapped to the domain of technical development, the resulting technical changes can be interpreted as those technical species which possess more adaptive traits in order to successfully deal with the changing environmental pressures. Hence, it can be inferred from the analogy that the increase in technical development occurs as a result of differential reproduction. This not only begins to offer mechanisms for understanding successful technical innovation but it also provides a potential structure of technical change which can be identified with a particular selection mechanism. The application of the selection mechanism in the Pearl (1925) curve to technical change assumes that technical growth can eventually be maintained at some particular point. This equilibrium position, is identified through the variable (L) and is often assumed to represent a finite position for technology, yet in this context this simple variable provides the action of a normalising function. That is, technical changes are normalised to the equilibrium position rather than providing a directional selection which takes advantage of stored mutations (Businaro, 1983). It is these two aspects of growth and selection which generate the information to identify technical maturity and rates of change.

The implications associated with this aspect of the analogy, is that it brings into question the applicability of three main causal relations which concern mutation, selection and equilibrium. Yet, it is only through the introduction of ideas on natural selection and mutation that the emergence of other less dominant relations, such as an heredity characteristic, appear. However, the evolutionary analogy used does not contain any causal relation between heredity and other evolutionary attributes. This natural limitation of the analogy can be found by identifying characteristics which are present in a base domain but absent in the analogy. A different analogical investigation is required if the idea of heredity characteristics of technical change is to lead to the description of how far the development of new technology is inherited from existing technical characteristics. Heredity offers the assumption that 'like produces like'. In a sense this can form the basis of a negative analogy or 'disanalogy' by identifying natural limitations. The basis for this positive analogy is formed from an analysis of a genotype, identified through an investigation of the analogical relationship between the reproduction of homozygotes and heterozygotes, and the development of new technology. To explain the implication of this analogy a detailed discussion is presented which can identify examples of the technical genotype. This analysis indicates the potential applicability of the reproduction analogy to technical change.

3.331 Using the Reproduction Analogy

The concepts of selection, heredity and mutation are common characteristics in any biological analysis of reproduction. General ideas of these common relationships, as described by the illustration, are identified by Lenz (1962) and whilst explicit use of such terms as selection and mutation are not used, the analogical description likens the development of technology to the process of bisexual reproduction. A brief outline of this analogy indicates that there is some degree of difficulty in expressing the similarities in the relation R, between bisexual reproduction, $\emptyset$, and technical development, $\emptyset'$.

In the analogical analysis provided by Lenz (1962), the two types of gametes are referred to as the inventor (female) and the existing invention or discovery (male). The main causal relations in the base domain are referred to as the opportunity of fertilisation and the actual point of conception. However, Gentner (1983) indicates that the most important aspect is the generation of mapping rules, whereby, relations could be matched with other relations. As far as the analogy can be transferred across domains in this context, the process is merely one of identifying possible causal relations, which can be seen as 'romantic' relational transfers. For Lenz (1962) these two characteristics in the reproduction domain can be interpreted as a structure of technical change, where the communication of technical knowledge, and the point of the origination of the idea, provide the basis for technical conception. At first glance, the analogy appears superficial. However, the generality of the analogy does hide a more formal theoretical base from which an understanding of technical change may be developed. This is particularly so in understanding the possible selection and heredity characteristics involved in technology change as if the function operated as a natural process.

By using Mendel's theory of factors (Smith, 1977) it is possible to begin to formulate some preliminary ideas concerning the nature of technical change. This analogical assumption concerns the 'male/female' relationship, in that the unlike factors in the relationship between inventor and existing knowledge will not merge in a first generation, but will form in the gametes and go on to form a second generation, as illustrated in figure 3.7.

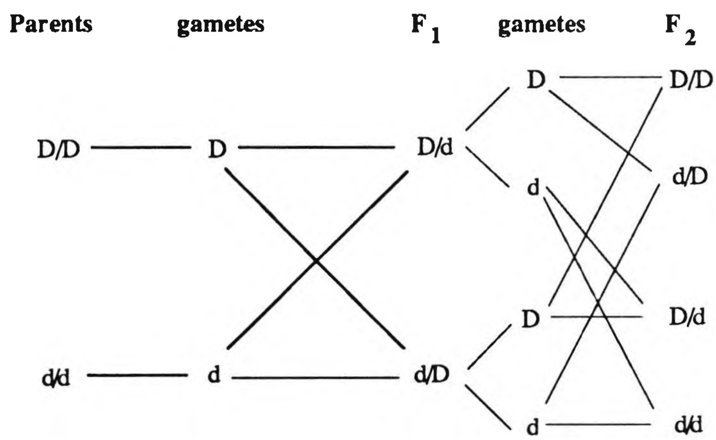


Figure 3.7 Mendel's theory of factors (Smith, 1977, p. 45)

The analogy provides an opportunity to provide a possible explanation for the presence of delay mechanisms in technical development, which can correspondingly be seen as a cyclic process of technical change. To introduce the analogical connection to the domain of technical change, an example is presented by using an analysis of technical changes in telephone exchange systems in the telecommunications industry.

3.332 Background to Technical Changes in Telephone Exchange Systems

The first automatic telephone exchange system to switch and control telephone calls was opened in Britain in 1912. The exchange utilised a mechanical system developed by Almon Strowger, and by 1922, the system was adopted by the Post Office as the standard telephone exchange. By the 1960's the Strowger exchange system had been developed and refined with switching and control mechanisms being based on electro-mechanical technology (TXK, UAX, TXE1, TXE3). Between the 1960's and the mid 1980's the development of semi-electronic exchanges provided the catalyst for the gradual replacement of Strowger exchanges. These new exchanges introduced new electronic technology which existed with electro-mechanical technology (TXE2, TXE4(RD), TXE4A). The changes in exchange technology are given in figure 3.8. These were developed as an intermediate step pending the development of a fully electronic exchange system (TXD) (Clark, McLoughlin, Rose and King, 1988).

At 31 March	Strowger % of Total	Crossbar % of Total	TXE % of Total
1967	100.0	0.0	0.0
1970	99.3	0.2	0.5
1974	88.3	3.8	7.9
1976	83.2	5.7	10.7
1980	72.6	8.2	18.2
1983	61.4	9.1	28.0
1984	57.1	9.7	32.3
1985	55.9	9.5	33.6
1986	53.9	9.3	34.6

Figure 3.8 the development of local automatic exchanges according to exchange type (1967-1986) (Data: Clark, et.al. 1989, p. 47)

Based on this simplified background for technical changes in the telephone exchange system, the analogical relationship between this target domain and the base domain of reproduction incorporating heredity characteristics holds. Mendel's theory of factors illuminates the mechanisms for delay between the electro-mechanical Strowger exchange system and a new innovative fully electronic exchange system, and the prominence of hereditary characteristics in new technology. The analogical relationship does not extend to a full second generation of technical species, simply because a decision was made by the Post Office in 1966 that no further orders of the electro-mechanical exchange system for small and medium exchanges would be made, that is, the habitat of these technical species was removed. This is identified in figure 3.9. Generally the analogy provides for a vivid expression for the development of telephone exchange technology, whilst indicating the possible implications for the delay mechanisms in technical development through an understanding of the hereditary characteristics in biological reproduction.

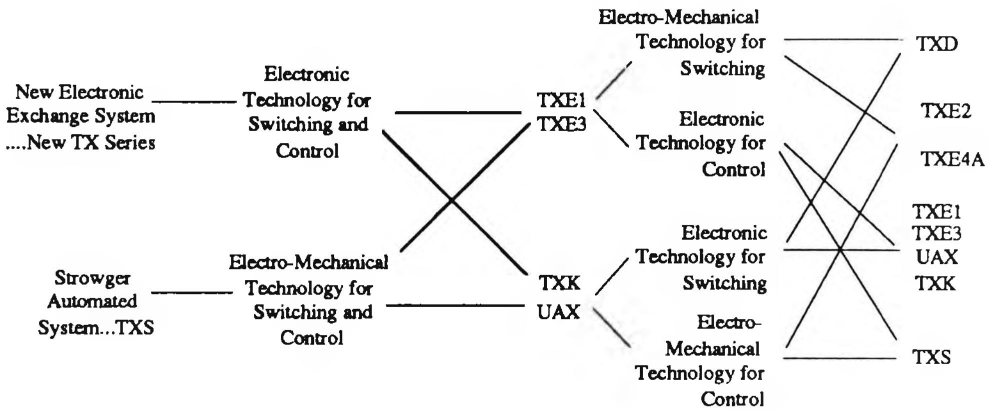


Figure 3.8 Mendel's theory of factors applied to the technical domain of telephone exchanges

If the analogy offered by Lenz (1962) continues to be entertained, a number of other factors highlight a degree of similarity between reproduction characteristics and technical development. For example, Lenz (1962) compares the growth of an embryo to that of the development of a technical idea, and identifies the period required for this new technical discovery as the gestation period. The birth is characterised by the disclosure of the invention and its development through economic support, as its nutrition. Other features of the analogy include a maturity time to illustrate the operational use of the invention, the period from disclosure to obsolescence as the natural lifetime and normal death as the technical obsolescence.

What the analogy does imply is the importance which is attached to the environmental character which can be identified by nutrition characteristics. Coupled with this, the idea is that the adaptive traits of the technology are developed within a form of a gestation period. The implication is a strong emphasis on the existence of an inbuilt selection and mutation involved in the process of technical change. However, the literature surrounding these analogical issues is nebulous, and does not portray a convincing and powerful argument for a more detailed analysis of the process of technical change. Those issues raised, do warrant further attention and it is the identification of anomalies within these present evolutionary analogies which provide some insight as to the limit of their use in developing further models in the target domain.

3.33 Anomalies in Using the Evolution Analogies

The development of the evolutionary analogies are useful to a degree, in that they provide some inductive insight towards the anagenetic structure of technical change. This has been identified by the common causal patterns between the base domain and the technical change domain. Nevertheless, although these strong parallels appear to exist, the analogy posits a number of assumptions which indicate the possible practical limitation of the analogy. Such characteristics influence any analysis of technical change. For Smuts (1926), evolution is not merely a process of change, but the development of new forms and new 'wholes'. These ideas pioneered a movement away from the mechanical view of evolution as the sole expression of external action. As a consequence, the nature of this evolutionary analogy, as it is applied to the process of technical change, assumes that events occur as if they are a natural process. These new events in the domain of technical development can be seen as organismic characteristics, constituting a degree of self-organisation and self-direction. The immediate analogical implication is to question parallels of the 'life' qualities of organisms with the 'life' qualities of technology, such as technical creativeness, growth and development. Although associations can be made, the biological evolution analogy is unable to introduce any explanation for such aspects. This degree of causality does appear to be optimistic. The question of the process of technical change being a natural process, is at best highly speculative and at worst misleading. However, insofar as a general growth theory may be applicable, the extent to which this biological analogy can be used to extend the characteristics of technical growth is debatable. The anomaly of this idea appears as a result of identifying the process as artificial. This is commonly found in economics, where technical change is regarded purely as an artificial process emerging from a changing economy.

Any analysis which extends beyond this question concerns why and how the various structures of technical change are maintained, and how the dynamics of these structures operate. This is a characteristic feature in the equilibrium hypothesis which the evolutionary analogies transfer to the target domain of technical change. Allen (1988) argues that this equilibrium structural assumption is fundamentally incorrect, and that evolutionary systems do not tend to any thermodynamic equilibrium, but rather evolve through a series of non-equilibrium states. It is this phenomena that leads to new technical structures and forms. From these arguments, technical development is a functioning process in the pragmatic sense, rather than evolutionary (Allen, 1988). The implication being, that technical changes which take place should not be regarded as structural changes, but rather, interpreted as the consequences of 'behavioural' changes. Ignorance of this structural base conceals the indicative problems of uncertain fluctuations and instabilities in technical change. For example, technical developments in telephone exchanges, which were cited earlier, illustrate that knowledge of both the structure and the behavioural implications were essential ingredients to a more complete understanding of the implications of technical change.

In the next section an account of the use of the production analogy is examined as a means of providing the appropriate structure for technical change models. This analogy is used to consider technical change as a result of changes in production characteristics, and consequently can classify technical change as an artificial process.

3.34 The Applicability of a Production Analogy

The use of a production analogy to describe the characteristics of technical change first emerged in the work of Ricardo (1971). Ricardo postulated that the application of new technology would lead to a drop in the price of consumer goods and a shift in capital composition. The result was that changes in wage rates and return on capital were seen as a direct consequence of technical changes, and therefore, it was appropriate to analyse technical changes through such characteristics of production. It was not until Schumpeter (1928), who hypothesised that all technical factors presented a strong influence on the direction of economic life, that a causal relationship emerged between economic laws identifying factors of production and the developing progress of the practical application of new technologies. A consequence of this causal relationship between economic growth and technical change, indicated that studies of production, distribution and consumption of wealth in economic growth were analogically representative for describing technical changes. For Schumpeter (1939), the introduction of a production function provided an initial mechanism which had the potential to describe all the technical processes of production. This was a first step towards a production analogy, and constituted the initial economic analogy for a structure of technical change. Whilst this initial analogy was insensitive to small changes in production, the introduction of new methods of production, or new products constituted a new production function of technical change.

This belief in the analogical relationship between economics and technical change, has developed through the production function, and is used to understand the necessary and inevitable course of economic growth in such a way as to promote the realisation of new technical orders. The analogy would incorporate all production factors which can be changed at will, and which could be constructed from all factual observations concerning the production state. For Schumpeter (1939), various interpretations for this analogy could be derived. For example, as technical progress is heavily influenced by the spirit of entrepreneurs, the production function could express all technical possibilities lying within the scope of the entrepreneur. In contrast, the analogy could also be used simply to reflect the full state of the technology in use. That is, the function would no longer provide a survey of all technical alternatives merely the technology which would be adopted. These were the foundations for the use of production analogy, and provided a distinction between the substitution and diffusion processes of technical change.

As the importance of the production function increased in the base domain of economic growth, the explanation of the analogical relationship to technical change was more carefully scrutinised. Critical discussions centred on whether the production function could actually reflect the actual physical state of any given technology. This function, not only depended on the accurate description of technical knowledge in terms of the means of production, the nature and volume of output, labour and capital factors provided by the analogy, but also in terms of the scope of the technical analysis. The potential of the analogy relied on how general the definition of the production function could become in terms of understanding technical changes. Further, the ability to transfer these similarities between the production characteristics of economic growth and technical change resulted from how far the analogy could be contrasted between macro-economic and micro-economic behaviour. Two other possibilities, initially identified by Schumpeter (1939) could be developed. These reflected the differences between a static and dynamic analogical analysis using this production analogy.

> " Although in the framework of a static analysis, production sets can be regarded as technical data, the change of one set to another in the course of time is so strongly influenced by economic factors that the dynamic analysis of technical development cannot ignore the economic effects on the formulation of new production sets."
>
> (Heertje, 1977, p. 142)

This analogical link, developed above, assumes that the target domain of technical change and the base domain of economic growth derived from production characteristics holds. This link helps to portray and explain technical changes through differences in the ratios between prices and factors of production as well as aspects of technical learning derived from productivity and investment characteristics. The effect is that technical change is explained through a growth model, where the expansion of technical possibilities is simply explained through the growth of production. Yet, different interpretations concerning the use of the analogy do exist. Using micro-economic behaviour, the analogy encourages an understanding of technical change in terms of: (i) a new means of production, (ii) new products and (iii) new relationships between goods. In these cases technical changes are very often derived from changes in the production parameter.

Although Heertje (1977) argues that the relation between micro-economic and macro-economic behaviour in relation to technical change is determined by the production analogy, there has been little discussion concerning the connection. The main problem for macro-economics is derived from the consequence of aggregating different types of labour and heterogetic products. One of the key differences in this explanation of technical change, is that macro-economic behaviour assumes that it is the production parameters which remain constant, and it is only the coefficients that change. The use of the analogy in a static context generally assumes that change in technical developments occurs as a result of a move from one production function to another. Micro-economic behaviour interprets this through the causal connection between the production function characteristics. However, macro-economics assume that such behaviour is irregular and that technical change can be derived from a shift in the production function or coefficient. This has also been refuted, as it has been argued by Heertje (1977) that such shifts are arbitrary, and that technical change can be more fully comprehended by observing changes in the growth of production and the growth of capital. Such differences in analogical interpretation add little comfort to those involved in analysing the dynamic sense of technical change, but the difference primarily lies with the depth of analysis.

3.341 Using the Production Analogy

Much of macro-economic behaviour links the wages, and interest rates involved with economic growth to that of technical change. The emphasis concerns entrepreneurial choice and elucidates the available technical possibilities from wage-interest curves and the wage interest frontiers. The mapping relation which holds is based on the implication that the rate of interest is equal to the rate of growth of capital, hence, consumption which is equal to the rate of growth of capital. Therefore, the production analogy links the growth of capital to be isomorphically related to the growth of technology.

In each of the three examples given, the technical possibility is assumed to function like that of a growth curve. A different growth curve reflects different technical possibilities derived from associated wage rates of production and interest rates (that is a characteristic linked to investment). In figure 3.10, it is shown that each successive new technical development dominates the previous. The result is that technical change is economically defined as 'unconditional'.

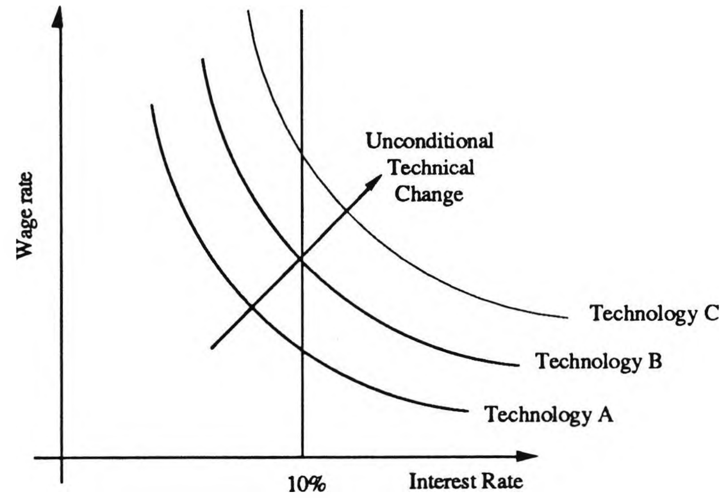


Figure 3.10 unconditional technical change as defined by a production analogy

Figure 3.11 is used to illustrate how technical change is dependent upon the rate of interest, or a particular wage rate in the production analogy. Technical change results from a decision to adopt a new technology based on the curve characteristics in relation to the two axes. In figure 3.12, the problem of cyclic variations in technical change is identified through the production analogy. In this example, technical change can occur at two particular points, with the decisions concerning technical change being bounded by the interest rate figures.

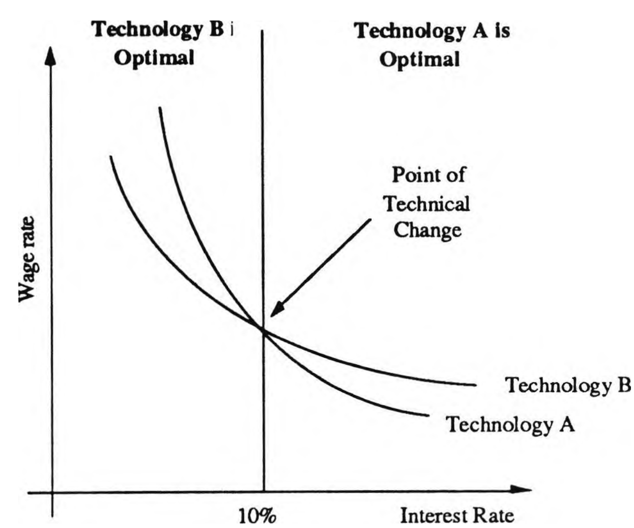
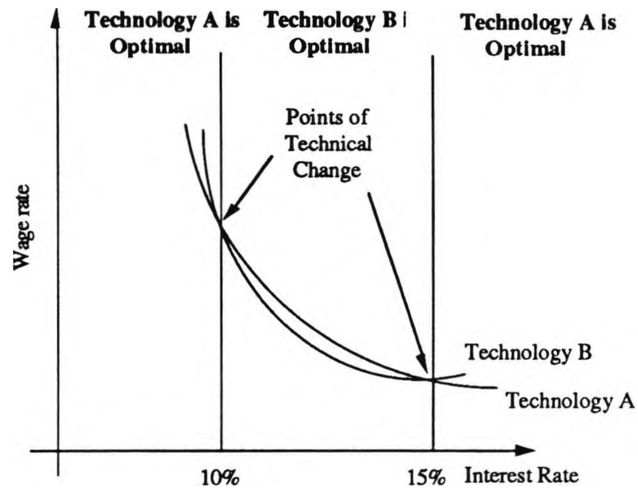


Figure 3.11 technical change dependent on one interest rate value



Figures 3.12 technical changes defined by the limitations imposed by interest rates

The key characteristic in using this analogy is the implicit use of the switch mechanism of interest rates to initiate technical changes, it implies an analogy which derives an stability position for the switch mechanism. Although this does not present the complete structure in terms of the analogy, this is expressed through utility and demand functions developed within the base domain. Although the assumption here is that the analogy illustrates the process of neutral technical change, non-neutral changes provide similar characteristics, but emphasise different switch points and curve dynamics.

3.35 Some Anomalies in the Production Analogy

These production analogies do provide a relatively coherent framework for explaining the successive production of technical mutations, whilst continuing to contain the adaptivity of new technology through a strong adherence to the equilibrium hypothesis. (Dosi and Orsenigo, 1988). Whilst the evolution analogies have failed to provide the insight in terms of economic criteria for understanding technical change, particularly because of the limit to which the analogy could be extended, the production analogy has provided an alternative means of expression. The production analogy corresponds favourably with the idea of equilibrium and mutation characteristics, but within an alternative domain to evolution. In this context, technical progress, or evolution is governed by the graphical interpretation of successive production functions. The analogy illustrates that each function is able to strive for some form of economic equilibrium. Further, the production analogy provides a strong identity to technical mutations, with the effect of introducing variations on neutral, labour saving or capital saving new technology. However, the analogy is structured to assume that technical change is a simple process of moving from one technology (existing) to another new technology, for example, from neutral to capital saving. Robinson (1979 and 1980) provides this generally adopted assumption in her models. But single technology change is a diminishing characteristic to the extent that invariably, the process is one of a multi-technology change, and one which this production analogy appears incapable of explaining.

The most important aspect of the analogy is the dynamic link between economic growth and technical development. The argument presented above does reflect such an analogical relationship, but the problem with identifying these shifts in the production function is that they simply may not be indicative of technical characteristics. The anomaly is that the shifts, which the analogy assumes correspond to technical changes, may lie outside the boundary of the target domain. That is, changes in the production characteristics may occur as a result of factors which have no causal link to the target domain. The implication is that the analogy can give an inaccurate picture of technical developments. An additional problem is that the analogy rarely offers any explanation for the cause of the technical movement, merely an alternative form of representation. In such instances technical change seems to be explained in terms of changes derived from the emergence of a new method of production, in other words, technical change! This is a circularity that does not provide an adequate explanation.

> "... the fact that we cannot explain technical change in the sense of predicting the character and timing of new technology on the basis of its causes does not exclude the possibilities of contribution to the understanding of essential aspects of the process of technical change."
> (Heertje, 1983, p. 47)

This degree of causality between: (i) interest rates, (ii) output and (iii) capital, which links economic growth and technical change, often presupposes that the process of technical development as an optimising one. The assumption is that with a particular technical change is may be possible to provide a maximum growth rate of capital. However, this assumption takes the causal relation beyond its analogical status insofar that the degree of similarity is substituted for a transitive inference between the two domains. This violates all aspects of the analogy and renders the implication of technical change as purely an arbitrary concept.

In the study of technical change the two main themes of evolution and production have illustrated some strong causal links through the use of particular analogies. Although certain anomalies exist, these analogies present the core mechanisms for analysing technical change. However, there are a number of analogical offshoots. A brief outline of different analogies is given below, and a link between the two themes of evolution and production is illustrated.

3.36 Other Analogical Interpretations

These two analogies, of evolution and production, have been traditionally used as the structural platform for models of technical change. It is from this that a general description of the characteristics of technical change, principally in the areas of growth, diffusion and substitution, have been developed. Many other analogies have developed from these primary associations, with the consequence that a plurality of models have emerged from the availability of multiple analogies. That is more than one analogy has been used as the structural basis of a model. The desired effect is to try to bring a more comprehensive explanation of technical change in to these models. For example, Robinson (1979) integrates structural assumptions concerning an implicit economic and evolution analogy. Limantoro (1985) uses analogies in engineering and economics to provide the structural assumptions of the model. The link of using a number of different analogies in technical change models is clearly made by Davies (1979).

Some early attempts to model the process of technical development, and in particular technical diffusion, likened the spread of new technology to that of a viral disease. In these technical change models, which used such an analogy, the critical point in the process appeared as that point in time when the technology became known, which took place through knowledge diffusion. Thus, whilst the primary analogy could be accepted in terms of a viral infection, a supplementary analogy concerning how knowledge acquisition was also required.

Other models are based on an analogical relationship between knowledge and information and technical change. In Isensen's (1966) model, the rate of change of technical information (I) was dependent upon: (i) the number of scientists (N_0), (ii) the average productivity factor per scientist (c), (iii) a time unit (q) and (iv) a finite limit (L). This rate of change of information could be regarded as a rate of technical change. The model assumed that the causal relationship in the analogy could be defined as in [11]:

$$\frac{dI}{dt} = q.N_0.e^{ct((L-I)/L)} \quad [11]$$

Similarly a molecular analogy, which is derived from the Hartman (1966) model, assumes that the rate of change of molecular motion depends upon: (i) the size of the molecule, (ii) the size of the possible collision area of the molecules and (iii) the number of molecules in a gas. This provides a strong analogical basis for modelling the rate of change of technology. However, one criticism of this was that the gain in molecular motion could only be accounted for by the number of existing molecules and therefore the gain in the rate of technical change could only be accounted for by existing technologies. Indeed, the analogy proved to be an inadequate mechanism for analysing technical change (Limantoro, 1985).

Analogies such as these, do provide a fundamental basis upon which a structural interpretation of technical change can be derived. This is one of the most positive attributes for the use of analogies in the context of understanding technical change. At the same time, it is essential that analogical usage does not overstep its natural limitations. For example, the most apparent limitation in using an analogy is the identification of the potential distinguishable characteristics between the target domain and the base domain. The impact creates the impression of the emergence of anomalies in the structure, and the behaviour of the target domain becomes more familiar. As a result the structural foundation in the base domain, which is used by the technical change model through its analogical relation, is called into question with the implication that the base domain characteristics can not be exclusively bound to the target domain. As a consequence, the analogy which is used can sometimes describe certain events which do not belong within target domain characteristics. Thus, in a modelling analysis of technical change, the use of a particular analogy may not be able to disentangle the causal relations and parts which are independent of the known anomalies which are assumed to operate in the target domain.

To overcome these problems, the most recent 'breed' of analogy has emerged which utilises not the single analogical orientation as the basis for an explanatory model, but uses a multi-analogical foundation. Rather than providing an extended analogical analysis, these multi-analogies focus on the commonalities of each analogy rather than explaining their individual anomalous characteristics. The assumed benefit from this approach is that the combinatorial relation of the two analogies can present a more detailed account of a structure for technical change models. For example, Sahal's (1979a) account of the development of new technology, considers the evolutionary mechanism of technical change through a cellular growth analogy, whilst linking certain attributes of this analogy to the economic characteristics of a production analogy. Other examples can also be found, Silverberg (1988) links technical change with the assumptions of a dynamical system analogy and a production analogy, and Pope and Hauptman (1988) link Bayesian assumptions with an engineering analogy to present a more informed model of technical changes.

Whilst such analogical investigations do provide a more informed analysis, the anomalies present within the singular analogy still remains. What strongly emerges is that the multi-analogy concept can only operate with regard to the lowest common denominator. As a consequence, it becomes difficult to extend any model derived from this new approach beyond the natural limitations of this denominator.

3.4 The Impact of Anomalies in Current Analogies

According to Kuhn (1970), any new discovery commences with the awareness of an anomaly, that is, a recognition might be held that the nature of technical change violates the induced expectations which are governed in the base domain of the analogy. The argument is such that Kuhn states:

> "It then continues with a more or less extended exploration of the area of anomaly. And it closes only when the paradigm theory has become adjusted so that the anomalous has become the expected....and until that adjustment is completed- until the scientist has learned to see nature in a different way- the new fact is not quite a scientific fact at all."
>
> (Kuhn, 1970, p. 52)

The emergence of anomaly is not purely deduced from violated expectations, but also from the interpretation of the descriptions used. Kuhn (1970) expresses this by comparing a physicists' and chemists' analysis of whether a helium atom was in fact a molecule. To the chemist, the helium atom behaves as if it were a molecule with respect to the kinetic theory of gases. To the physicist, the atom is not a molecule because it does not display a molecular spectrum. Thus, the analogical link between the atom and molecule is verified, or refuted, according to the interpretation given by the analogical attribute. Rather than accommodating such attributes and explaining the differences in these mapping relations, Kuhn's (1970, p. 53) statement suggests that the need is to find an alternative analogy which can fully correspond to the attributes found in the target domain. These points can usefully be placed in the context of the emerging anomalies found in the evolution and production analogies of technical change. Rather than accommodating the differences in each analogy employed, which is achieved by using the multi-analogical orientation, the structure of the new technical change models needs to rely on a new analogy which accommodates and explains the differences which have already been identified. That is, a new coherent structure for technical change.

The inspiration that is required for a reinterpretation or revision appears to be this awareness of a particular anomaly or set of anomalies. Such a characteristic has to be recognised as not 'fitting in' with the existing explanation or, an inability to describe the pattern or property of a particular characteristic. To derive a new analogy requires two particular functions: (i) a bridgehead and (ii) systemacity. If a bridgehead is to serve its function then some taxonomic attributes in one analogy must overlap substantially with attributes of the new analogy. For example, in evolutionary terms the nutrient media for technology has to be explained by the analogous oxygen requirements of cells. In the new analogy, the question must be how would such an explanation be incorporated. In trying to locate a new analogy, a likely place to start is to look for an overlap, but nothing like a set of shared characteristics is needed, as it is probable that such an exercise would not be fruitful. What this implies, is that some objects which can be grouped together in a new analogy should also have the ability to be grouped together in the old.

To illustrate this point, much of the development at work for a new analogy derives not from an exploration of the analogies used, but in an investigation of the purpose behind the use of the analogies in the various models developed. Analogies are instruments to be judged by their comparative effectiveness in promoting thc ends for which they are put to use. In Chapter Two, an indication was given that such attributes of stability, uncertainty and evolution were generally reflected in these models. These attributes have to be reflected in the core of the new analogy. This would represent the local region of the analogy. Outside this area new attributes may give new insight into the structure of the target domain. For Gentner (1983), this is not just a question of finding the appropriate analogy, but includes a means of finding the appropriate systemacity. For a new analogy brings a new set of concepts. It is the degree to which these concepts can be applied to the target domain that determine the potential of the analogy, that is, its systemacity.

3.5 Conclusions

At the outset, this chapter was designed to determine two considerations: (i) how are the structures used in technical change models determined? And (ii) to identify how a more comprehensive structure might be sought. It is from these considerations that the following conclusions are made.

(i) Structural analogies. The use of analogies is part of scientific inquiry. It is concerned with the issue of matching two domains of knowledge by identifying commonalities in causal relations rather than in the elements themselves. The conclusion from this observation is that the essence of analogical inquiries lies in the ability to derive structural inferences concerning a target domain without direct reference to it. This use of analogies provides a means for structural reinterpretation of the target domain, providing evidence for new facts, mediation and also new theoretical insight. This is the how the structure of technical change within the models is currently being determined.

(ii) Analogies in use. Structural analogies provide the fundamental assumptions in defining the particular structures in technical change models. The use of evolution analogies in defining a technical change structure does present a degree of acceptability, particularly in terms of growth, substitution and diffusion models. However, the natural limitations of the analogy in terms of the characteristics of equilibrium and the assumption of natural qualities indicates that there is a limit to any generally proposed structure. Extending the analogy beyond its limits, to explain the characteristics of uncertainty and instability, suggests that the usefulness of these evolution analogies is doubtful.

The use of the production analogy presents a means of providing an economic interpretation of the structure of technical change models. The dominant use of such an analogy before the 1970's indicates that its acceptability as a general structure for technical change has diminished. Whilst the analogy does provide a strong indication of the mechanisms which produce technical changes. The assumptions of rationality, equilibrium, and an inability to explain characteristics derived from an evolution analogy, have indicated the natural limitation of the analogy.

A number of other analogies have emerged as the structural basis in technical change models. These include: (i) the gas analogy and (ii) the information analogy, but the conclusion is that they have had little if any general acceptance within the literature.

(iii) Problems for a comprehensive technical change structure. The limitations in single analogical use has produced a number of models which attempt to derive a structure based on a multi-analogical context. Whilst the assumption is that integrating the characteristics of more than one analogy can provide a more extensive structural description, the conclusion is that the structure exhibits only those characteristics which are common to both analogies.

(iv) "...Seeing nature in a different way..." (Kuhn, 1970, p. 52). There is a need to develop a new interpretation for a comprehensive structure of technical change. In order to achieve this, the existence and location of this new analogy has to be determined. The core of this new analogy must include the characteristics associated with stability, uncertainty and evolution. In addition, the analogy has to include the appropriate systemacity, that is an acceptable form of organisation which utilise particular relations between these general characteristics.

Drawing upon these conclusions, the general structures of technical change, which are used in the models identified in Chapter Two, are assumed to be based on an analogical association. This use of analogies in models of technical change is dominated by: (i) the evolution analogy and (ii) the production analogy, but these are not applicable as comprehensive modelling structures for technical change. The implication is that a new form of analogy must be used in order to generate a reinterpretation of the structure for technical change. Establishing a more appropriate analogy is essential in order to produce a new breed of technical change model, which can provide the necessary preparations for future technical changes. The existing knowledge of technical change, indicates that the analogy which is to be used, must overlap with the general characteristics of stability, uncertainty and evolution identified in Chapter Two. On the assumption that any systems based study contains an ability to utilise such characteristics within a number of system structures, how is it possible to demonstrate the use of an appropriate system analogy in defining a new general structure to be used in technical change models? Chapter Four documents the inquiry carried out to answer this question, detailing the process which establishes the most appropriate system analogy for inferring a structural model of technical change.

PART TWO

CHAPTER FOUR

AN ADAPTIVE WHOLE SYSTEM ANALOGY TO STRUCTURE TECHNICAL CHANGE

4.1 Introduction

Possibly the most enlightening image which shines through from Chapter Three is how technical change structures used in the models are derived from certain analogical approximations. In a perverse manner it is this awareness of such modelling limitations which allows for the emergence of new ideas (Kuhn, 1970). For economists, engineers and sociologists, the problems associated with technical change have always been concerned with how to bring scientific rigour to this particular study. This has principally stemmed from a failure to overcome the problems of deductive thought, and has resulted in an inability to derive any form of coherent set of empirical evidence, either from first principles and even from available data. Economists and other technical change analysts have relied on a series of assumptions and equations built up from analogical base domains. Their attempts have drawn upon various ideas which have been developed through the use of aspects such as: (i) the economic laws of growth and compensation, (ii) evolutionary theories, (iii) the theories of regulation, defined by Boyer (1988) in terms of socio-economic tuning and (iv) equilibrium theories.

This chapter demonstrates the logical necessity for the use of a system analogy in defining a general structure to be used in a new breed of technical change model. Divided into three principal sections, the first section of Chapter four discusses the process of using a systems analogy to provide a comprehensive structural description for technical change, and identifies a number of systems analogies which can provide the potential for the description of technical change. It concludes with a discussion on the use of the adaptive whole systems analogy, by analogically deriving a structural model of technical change. In a second section, the analogical relationship between the adaptive whole system description and known characteristics of technical change is determined. Using the process of analogical reasoning discussed by Sierocki and Tchon (1982), and using Beer's (1984) methodology of topological maps, the structure of technical change is theoretically examined in terms of the characteristics associated with the adaptive whole system. A theoretical simulation of this technical change structure is presented and illustrates that a need does exist for a more refined adaptive whole systems analogy in determining an acceptable structural model of technical change. The conclusions from this analogical enquiry, and the simulation results, are discussed in a final section.

4.2 Analogical Ideas in Diagnosing Systems

An interpretation of a systems analogy which provides a conceptual description for a structure of technical change, assumes that the meta-theory of the analogy becomes the design pattern for that structure. For Counelis (1989), this meta-theory consists of the relationship between: (i) the domain the analogy resides in, (ii) the relations held within that domain and (iii) the known relations held within the target domain. Identification of this meta-theory produces the coherent means to conceptualise the design pattern for the structure of technical change defined in [1] (Counelis, 1989, p.3).

$$A_c = \text{def}\, f \, \Sigma \, [\, (x_1 : X) :: (y_1 : Y) \,] \qquad [1]$$

To determine this meta-theory, three aspects have to be established which are linked to the work of Sierocki and Tchon (1982). That is: (i) the location of the core analogical region (Σ), (ii) a set of statements constructed from the analogy ($x_1, x_2 \ldots x_n$) concerning the system (X) and (iii) known statements regarding the domain of technical change (Y). The implication of this, is that a set of statements concerning the structure of technical change ($y_1, y_2 \ldots y_n$) can be inferred from X without direct reference to the structure of Y, as $(X,Y) \in \Sigma$.

4.21 The Core Analogical Region

The location of the core analogical region (Σ) must be reflected in the importance of structure attached to both systems and technical change. For Systems Science, the design of structures is linked to the principal roles of division and integration. This derives the ability to organise, design and diagnose systems.

> "...the argument is that although naturally integral it must be divided, as long as the division is convenient. In systems research we must look out for this division. Where there is a division, the system is uncoupled and it is here that many coupling aspects are considered- queues, dams, feedback and negentropy etc."
>
> (Beer, 1961, p. 15)

This is critical to the domain of technical change. The pluralistic attempts to diagnose particular technical change structures have riddled the genuine domain of technical change with divisions, but still lacks the characteristic means of integration to develop a comprehensive structure. For Systems Science, there is the assumption that system characteristics can take place in a number of divisions. For example:

> " The world is, as Aldous Huxley once put it, like a Neopolitan ice cream cake where the levels - the physical, the biological, the social and the moral universe- represent the chocolate, the strawberry and the vanilla layers. We cannot reduce strawberry to chocolate - the most we can say is that possibly in the last resort, all is vanilla, all mind or spirit."
>
> (von Bertalanffy, 1968, p. 48)

Dooyeweerd's (1958) philosophical study of these divisions or modalities, states that situations do contain a variety of these modalities. To understand the structure of any situation there is a need to identify the connections between these modalities. Thus, as de Raadt (1988) explains, a symphony might manifest itself in several modalities, that is: (i) a physical modality emphasising sound, (ii) an aesthetic modality conveying beauty and (iii) a historical modality indicating the musical period. The same argument can be levelled at the situation concerned with the structure of technical change. Confronted with different types of modalities such as: (i) economic, (ii) social, (iii) cultural and (iv) technical, the need is to develop a structure which encapsulates rather than obliterate the variety of the situation. According to de Raadt (1988), the ability to generate this structure is built on one or more foundation modalities which provide the connectivity.

The identity of this core analogical region can be defined by this shared sense of connectivity. That is, to develop a structure of technical change through the coupling of structures derived from system descriptions. For Sahal (1979b) technical change is a result of a fundamental change in the complexity and other systemic properties of the whole, as distinguished from the properties of additions to and subtractions from the aggregate. The implication is that it illustrates a degree of premeditation, a deliberate transition of preconceived information to the development of a new systemic structure of technical change (de Raadt, 1988). Describing technical change in this manner assumes characteristics of self-generation and self-constraint, lying in a historical foundation, and assuming that changes operate as an irreversible function. These particular implications assume that the structure of the system analogy has to play a crucial role. This means that a reinterpretation of current thinking concerning the structure of technical change does depend on how an appropriate system analogy (X) can be found.

4.22 Defining the System Analogy

The system analogy (X) must belong to (Σ) and connect the use of particular divisions with the identity of a comprehensive integral structure. The formal identification and the subsequent use of particular systems analogies, has come under increasing academic scrutiny in recent years. The results of these investigations (Flood, 1990, Robinson, 1990, Atkinson and Checkland, 1988) have led to a diverse set of systems analogies which accommodate different meanings and rationalities, whilst stressing a particular systemic structure.

The degree of cohesion amongst these analogies is determined by the type of basic description concerned with the concept of 'system'. Until recently such descriptions have been regarded as somewhat vague (Atkinson and Checkland, 1988). The systems structure of the open system, first identified in von Bertalanfy's (1968) 'General System Theory', became a powerful system description which enriched traditional scientific thought. The concept of this open system became an integral mechanism in the promotion of concepts associated with efficiency and effectiveness (Flood, 1990). With such a strong concept, its use became more analogical, and developed in other domains where its attributes were used to understand, investigate and represent alternative events other than that of the living organism. As such, the analogical orientation of the open system was used to search for and explain underlying regularities present in other domains, whilst emphasising its organising characteristics (Burrell and Morgan, 1979). Whilst, the general analogical use of the open system has diminished in recent years, it has been the basis of a number of derivative analogies. These have been classified by Atkinson and Checkland (1988), in terms of an adaptive whole system analogy. This classification does not imply that the analogies are loosely bound to one general characteristic, but is based on the hypothesis that it is possible to identify and discern different types of adaptive whole systems in practice. A number of examples are shown in figure 4.1.

These adaptive whole system analogies offer far more than just taking heed of the environment, and go far deeper than providing a simple mechanical equilibrium model developed from the earlier centuries (Burrell and Morgan, 1979). The adaptive whole system analogy can include the structural characteristics of a homeorhetic system, capable of seeking new developmental pathways through successive instabilities. As an autopoietic system, the analogical structure can pay particular attention to its recursive and regenerative characteristics. This is a system in which the sequence of events in primarily governed by the relationship between the structure and the environment, in which the environment acts as a governor, selecting possible states which are produced by the structure. Flood (1990) states that the viable system parallels the adaptive whole system. In this analogy viability is the key system characteristic which describes the importance of learning, recursion and control in a dynamic sense.

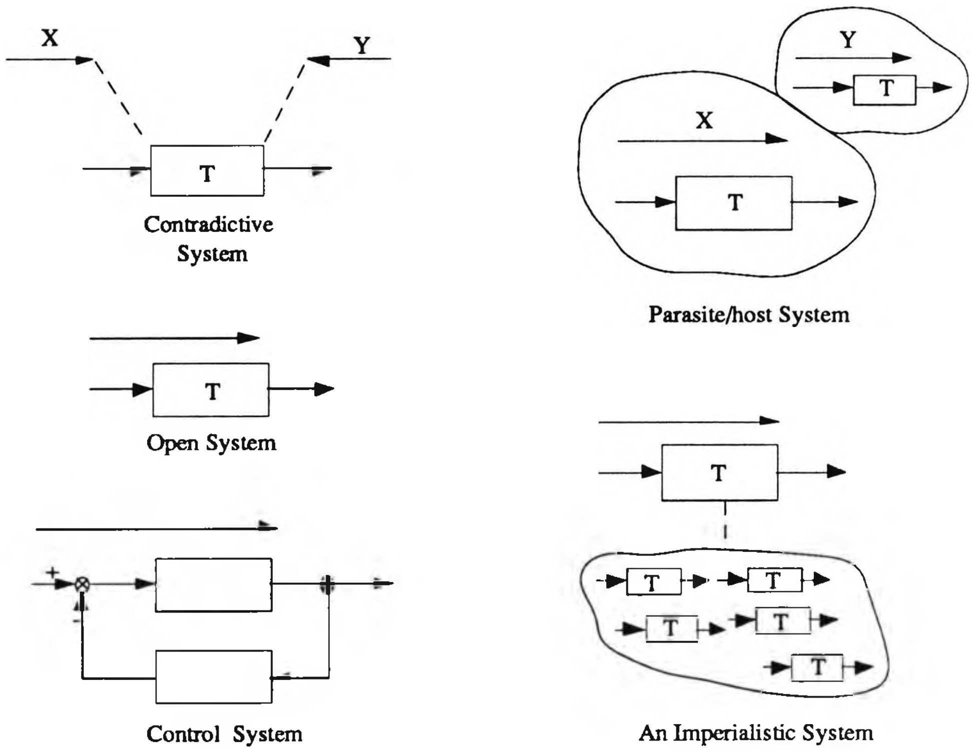


Figure 4.1 possible adaptive whole system analogies (Atkinson and Checkland, 1988, p. 719)

The importance of variations on the adaptive whole system analogy cannot be stressed enough. It is essential to understand that whilst these analogies may prove useful in particular target domain contexts they also radically effect the kind of analysis which is made (Boland and Greenberg, 1988). For example, the more ambiguous a situation, the more important are the analogies which are used to order the situation, and make sense of the events. The implication is that all these adaptive whole system analogies are useful, but a more informed insight can be produced by utilising a generalised adaptive whole systems description at an initial stage before moving towards more specific adaptive whole system analogies for a detailed analogical explanation.

The analogy does have its critics, Flood (1990), attacks the analogy on two counts: (i) through its construction from natural science building blocks, and (ii) on its possible return to a systems orientated positivism. But this does not deflect from the structural implication of using the adaptive whole system analogy. Indeed Flood (1990) proposes other system analogies which may be applicable. The organismic, cultural, power and even the 'black box' analogy are systems orientated, but the problem is that, whilst they do possess a description of the systems structure, other characteristics are incorporated which relate specifically to the organism or to cultural aspects outside the systemic description. Indeed, the function of these analogies is to identify particular elements rather than relations, as opposed to the organising concept, where the relational concepts of division and integration are critical. An emphasis in using such analogies to reinterpret the structure of technical change would fail, simply because the cultural, power and even organic analogies do not belong to the defined analogical region, Σ. If the analogical region was concerned the power attributes associated with systems and technical changes, then the choice of analogy would be reflected by adopting a particular power system analogy, and the characteristics $(y_1, y_2 ... y_n)$ would appear different.

The adaptive whole system analogy does present a strong systems structure, which not only provides a format for illustrating connectivity, but also contains a high variety channel. A high variety channel is defined by Beer (1985) as that property which develops the tendency towards isomorphism, rather than homomorphism. In many of the analogies used in examining the structure of technical change, a low variety channel has operated. This homomorphic structure introduces an increased probability of particular attributes being described in one analogical property whilst being absent in another. In Kuhn's (1970) example of the analogical structure between the atom and the molecule, introduced in Chapter Three, the different interpretations used by the chemist and the physicist illustrate that different variety channels were operating in the analogy. For the chemist, the variety channel used, defended the analogical structure. The physicist, using assumptions regarding the molecular spectrum, provided a different variety channel and rejected the analogical relationship.

For the adaptive whole systems analogy, its particular benefit lies in its ability to provide a degree of connectivity whilst influencing any explanation of technical change through a systems base. It is this characteristic which makes an adaptive whole system analogy far more informative than others which have already been tried and tested. In addition, the transdisciplinary nature of systems, presents a deeper analysis than any superficial analogies, and attempts to represent specific correspondences between the structure of adaptive whole systems and technical change (Mayne, 1979).

4.23 General Analogical Characteristics of the Adaptive Whole System

The adaptive whole system contains certain analogical attributes, (x_1, x_2 ...x_n) with regard to its structure. Three general analogical characteristics are defined as: (i) the structural content of the system, (ii) the dependent relations and (iii) the information flow.

For Checkland (1980), the minimum structural content of the system consists of three subsystems of: (i) an awareness system, (ii) an operational system and (iii) a monitor and control system. Considering the awareness which the adaptive whole system must gain before it can adapt; it has to appreciate the circumstances in which the adaptive whole system functions, and also acquire and maintain those aspects associated with the appreciative activity. The operational sub-system; this has to have available the information gained from the awareness subsystem, and its main activities will be those most closely associated with providing the system with the ability to adapt. In order to ensure that the systems operations are making a positive effect to the success of the adaptive whole system, it is necessary for the system to monitor and control its operations.

From the foregoing account, a description of the dependent relations can be provided. The operational subsystem is dependent upon information from the awareness subsystem, and the monitor and control subsystem is dependent upon the awareness and operational subsystems. The flow of information concerning the adaptive whole system is dependent on the activities of the awareness and monitor and control subsystems.

By identifying these three structural characteristics of the adaptive whole system from Checkland's (1980) and Atkinson and Checkland's (1988) works, an illustration of the overall structure of the adaptive whole system is presented in figure 4.2.

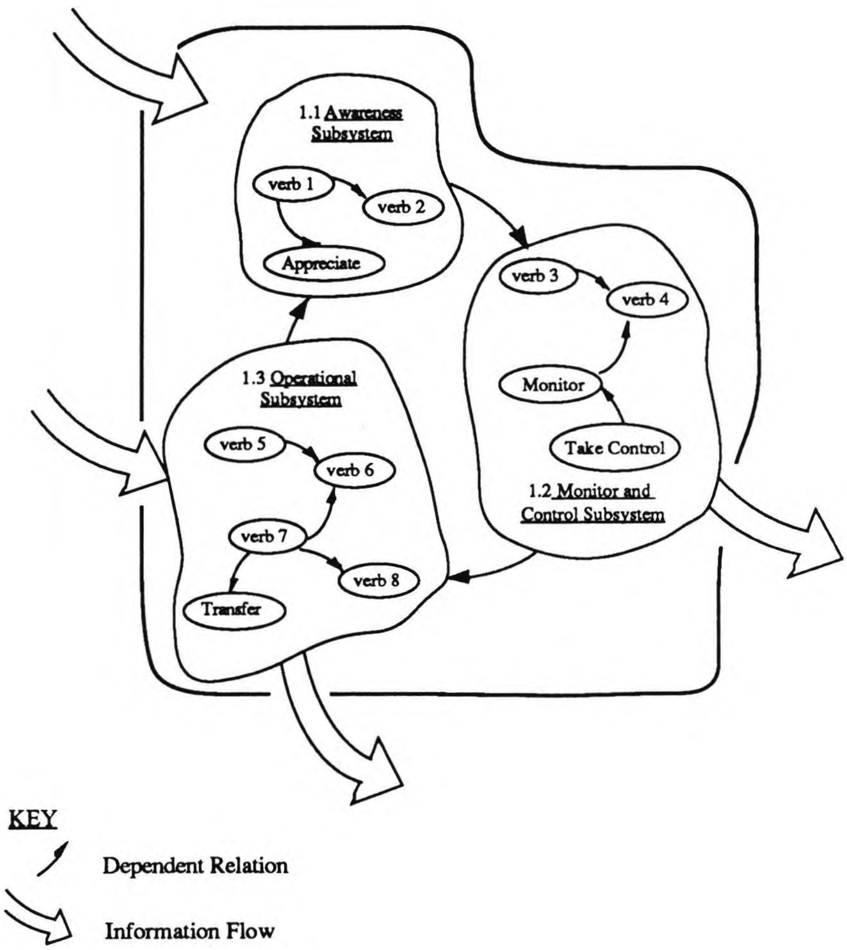


Figure 4.2 Checkland's (1980) adaptive whole system description (Checkland, 1980, p. 289)

4.24 Known Activities of Technical Change

From [1], it is essential that the analogical link Σ, provides the structural characteristics (y_1, $y_2 ... y_n$) of technical change (Y), by using the particular analogy adopted (X) and the known general activities associated with Y. Whilst Chapters Two and Three indicate that there are a number of activities which characterise technical change, by drawing from the conclusions of Chapter Two, three general activities can be defined. These are: (i) evolution activities, (ii) stability activities and (iii) uncertainty activities. From Chapter Two, evolution activities are identified as providing the basis from technical progression, indicating the adaptation of technologies between specified time periods. These activities are associated with: (i) technical competition, (ii) complimentary activities, which reinforce the particular technical style and (iii) contradictive technologies, which produce instabilities in the process of technical adaptation. Within the process of technical change, there are stability activities which are used to coordinate the dynamics of technical progression. This is carried out by reducing the effects of the size of the technical changes, whilst enabling the process of technical change to accommodate certain new technical improvements. These activities are linked with (i) financial controls, (ii) skill requirements and (iii) technical compatibilities. Activities generally associated with reducing the uncertainty effects in technical change are primarily concerned with identifying future technical changes from environmental action. The correct prediction of particular technical change reduces the problems of uncertainty within the process.

4.3 The Adaptive Whole System Analogy as a Part of Scientific Modelling

The symbolic proposition of [1] presents the argument that analogy consists of a two component description through which the first component (X) is likened (formally and/or substantively) to a second component (Y) which is the object of the analogy (Counelis, 1989). This proposition is part of a scientific process which aims to structure and test the activities of analogical investigations. It is based on a realisation that similarities may exist between two or more situations (Achinstein, 1964). The implication being that an analogy provides science in general with the means of analysing unfamiliar situations (Robinson, 1990). But, in addition, the role of analogy does not simply provide for a theoretical interpretation for the unfamiliar situation, it also provides a means of scientifically modelling that situation without direct reference to its dependent relations.

The potential of the adaptive whole system analogy is that it can be used as part of a process of scientific modelling. Beer (1984) provides one possible approach of scientific enquiry which contains an analogical basis, and refers to it as the methodology of topological maps.

In Beer's (1984) account of this methodology for scientific modelling, a four stage process is presented. The first stage is concerned with identifying a familiarity between two particular situations. This perception leads to the second stage which illustrates the familiarity between the two situations through the use of an appropriate analogy, and produces a conceptual modelling description. The basis for this conceptual model is presented from the analogical interpretation and is developed by using the identity of dependent relations found within the base domain and transferred across to the unfamiliar situation, or target domain (Winston, 1980). Having established this homomorphic association, a third stage is used to conduct a more detailed analogical investigation in order to illustrate isomorphic characteristics between the two domains. This rigourous formulation leads to a fourth stage, where a generalised scientific model of the unfamiliar situation is developed. In addition, the methodology continues by reflecting back on other samples of the class of analogy in order to establish whether a more detailed modelling account of the situation can be defined by an alternative example of the analogy. Beer (1984) refers to this part of the methodology as the 'yo-yo' technique. An adaptation of Beer's methodology for scientific modelling is presented in figure 4.3, indicating the relationship between System Science, the adaptive whole system analogy and the situation of technical change.

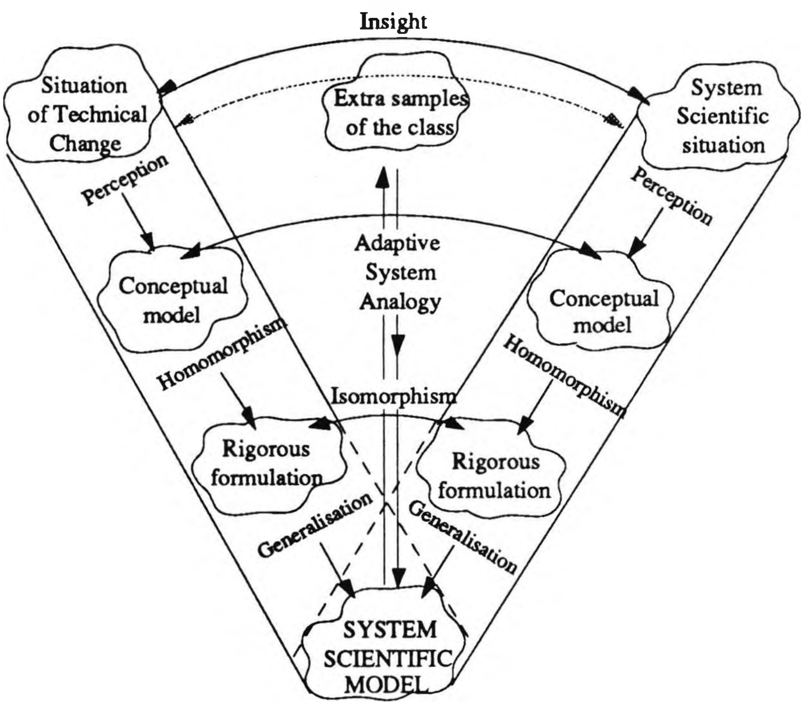


Figure 4.3 an adaptation of Beers account of scientific modelling (Beer, 1984, p. 9)

By including the adaptive whole system analogy in the proposition [1], and the methodological account of scientific modelling presented by Beer (1984), these two aspects provide the criteria by which a process of analogical reasoning can be conducted. It has already been established that the similarity, identified by the core analogical domain, Σ, exists between Systems Science and technical change, and that the analogy adopted can be described through the adaptive whole system $(x_1 : X)$. Thus the process of analogical reasoning can be carried out in four stages: (i) through the perception of similarities, (ii) defining the dependent relations in technical change through analogical insight, (iii) analysing the dynamics of the structure through rigourous formulation and (iv) a scientific model of the general structure of technical change based on the adaptive whole system.

4.4 Analogical Reasoning in Practice

A general outline has been provided concerning to the characteristics belonging to proposition [1], and to the four stages of a process of analogical reasoning, taken from Beer's (1984) account of scientific modelling. This section presents the findings from these four stages.

$$A_c = \text{def}\ f \sum [\ (x_1 : X) :: (y_1 : Y)\ ] \qquad [1]$$

4.41 A Perception of Similarities

The first stage of this analogical process defines the possible similarities between the characteristics of the adaptive whole system in the base domain (x_1: X), to the known activities in the target domain of technical change (Y).

It has been established that the known activities in the target domain are those associated with: (i) evolution, (ii) stability and (iii) uncertainty. The perceptions relating to the similarities between these three activities, and the activities associated with the subsystems of the adaptive whole system, expressed as: (i) operation, (ii) monitor and control and (iii) awareness, can be determined.

The activities of the operational subsystem have the necessary means to provide the basis for adaptive whole system transition. In a similar manner, the evolution activities associated with technical change provide the basis for technical transition. The similarity between the monitor and control subsystem and stability activities reflects that the activities of this subsystem present the means by which the oscillatory aspects of adaptation are reduced. The ability to recognise such activities is dependent on the function of an awareness subsystem, linked between the operational subsystem and the adaptive whole system environment. By using the activities of the awareness subsystem, a reduction in the uncertainty concerning future events of new technical products can be derived from information gathered from the environment and operational activities.

Identifying these similarities provides information concerning this process of analogical reasoning: (i) the communication of certain insights and (ii) providing the possibility for further analysis of an unfamiliar structure of technical change. Figure 4.4 provides the insights to be gained from the identification of certain similarities between the adaptive whole system and technical change.

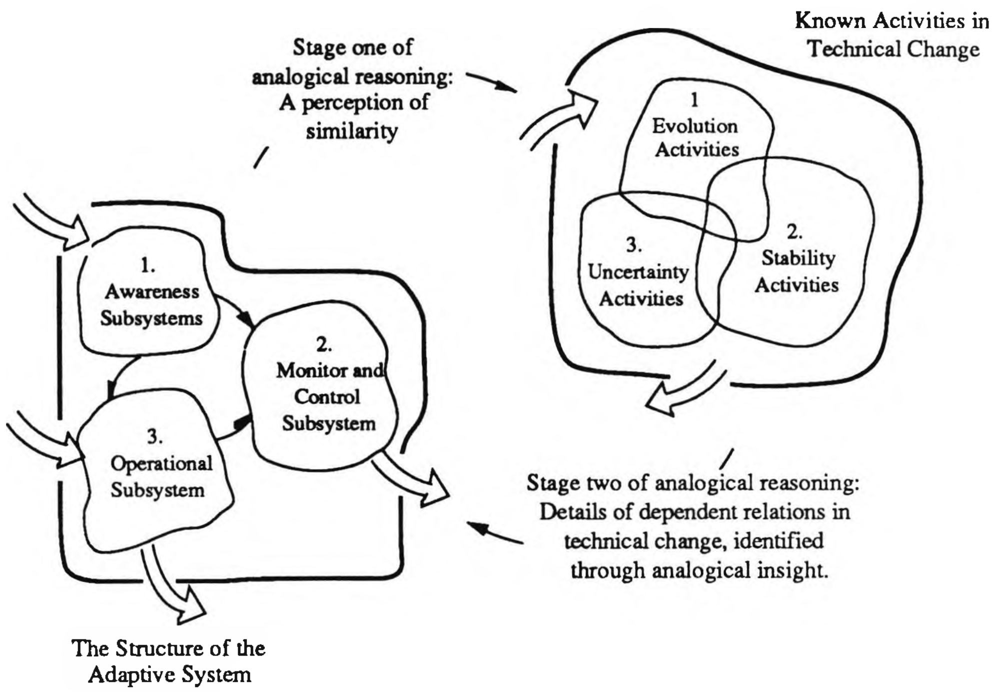


Figure 4.4 similarities between the adaptive whole system and technical change

Whilst this first stage of analogical reasoning has helped to reveal certain insights, it also helps to provide an initial perception of a possible systemic structure of technical change. By defining the dependent relations in technical change through the use of the adaptive whole system analogy, it will create a more insightful perception of the structure of technical change, rendering this target domain more exciting and informative.

4.42 Defining Dependent Relations for a Structure of Technical Change

The second stage of the process of analogical reasoning defines a conceptual model for the structure of technical change, using the analogical characteristics (x_1, $x_2 \ldots x_n$) of the adaptive whole system (X). The conceptual model provides the first indications of the structural characteristics (y_1, $y_2 \ldots y_n$) in technical change.

By using Sierocki and Tchon's (1982) theoretical framework, the identity of the dependent relations for a structure of technical change can be deduced by making an assumption that both the adaptive whole system (X) and technical change (Y) belong to the particular analogical region (Σ). Let R, be defined as a certain equivalence, weak or similar relation, such that [2] can be defined as:

$$(X,Y) \in \Sigma^R \qquad [2]$$

If there exists certain structural characteristics (x_1, $x_2 ... x_n$), defined as the properties of (X) than [3] and [4] are produced:

$$P = (x_1, x_2 ... x_n) \qquad [3]$$

$$P \in \Sigma \qquad [4]$$

The properties of P, are defined by the four characteristics associated with its structure, these being: (i) an awareness subsystem, x_1, (ii) a monitoring and control subsystem, x_2, (iii) an operational subsystem, x_3 and (iv) the position of the environment in relation to the adaptive whole system, x_4. The properties of the adaptive whole system can be represented by a quadruple, (x_1, x_2, x_3, x_4). A more detailed analysis of the adaptive whole system structure identifies the actual transfer function for adaptation in terms of the operational subsystem. Assuming that this subsystem operates over uniform time periods (t_1, $t_2 ... t_n$), the actual adaptation activity can be represented by [5]:

$$x_3^{t1} = f\,(x_2^{t1}, x_1^{tn\text{-}t1}, x_4^{tn}) \qquad (5)$$

From equations, [2], [3] and [4], it can be inferred from the relation, R, that the properties P′, belong to Y, without any direct reference to Y, and where P′ ≡ P.

$$P' \in Y \qquad [6]$$

$$P' = (y_1, y_2, y_3, y_4) \qquad [7]$$

The result defines the structural properties of Y through the characteristics of (y_1, y_2, y_3, y_4), which can be interpreted through an analogical structure described in [5], and linked to the known activities associated with the target domain, Y.

To achieve the analogical interpretation from [5], a definition of the input and output variables needs to be established. For this particular analysis, a single input and output variable defined in terms of a technical state, (T) is used. At this stage no assumption is made concerning the characteristics of this technical state, as the process of analogical reasoning is concerned with the structure of technical change. The initial input to technical change is given as (T^a_0), where the value, a, reflects the actual technical state. The output from the process of technical change at each uniform time period is given as (T^a_{t+1}) with the output value at t_n, reflected by the technical state $(T^p_{t_n})$.

By referring to the insights discussed in the first stage of analogical reasoning, a similarity was expressed between the activities of technical change and the subsystems of the adaptive whole system. The three areas of similarity now provide a means by which the dependent relations in a structure of technical change can be defined.

The relationship associated with stability (S) in technical change, and a monitor and control subsystem (y_2) expressed through an analogical interpretation is given in [6]. The stability activities (S), are aimed at ensuring a cohesiveness in technical change. Whilst it is not designed to maintain a particular technical product, it requires certain controlling activities concerning the nature of the actual technical state. By monitoring these particular technical states, the stability activities can reduce the potential of variety proliferation which may induce oscillatory consequences in technical changes. This interaction is expressed in [8]:

$$y_2 = f\,(S) \qquad [8]$$

A second similarity between an awareness subsystem (y_1) and the activities associated with technical uncertainty (U), provide the basis of a second dependent relation in a structure of technical change. Whilst, y_1 provides the information link between environmental activity and the operational subsystem (y_3), the activities of uncertainty are concerned with the ability to forecast new technical states (T^a_{t+1}) from the current state (T^a_t), and existing assumptions concerning the future unknown technical state (T^p_t). A structure of the uncertainty activities is defined by [9], whilst an uncertainty value regarding the forecast of new technical states at time t+1, can be expressed by the difference between the current and assumed possible technical states known at time, t, as in [10]:

$$y_1 = f\,(U^{nT}_{t+1}) \qquad (9)$$

$$U^{nT}_{t+1} = T^{p}_{t} - T^{a}_{t} \qquad (10)$$

The final area of similarity between the operational subsystem (y_3) and the evolutionary activities in technical change (Ev), illustrates the identity of a final dependent relation. The function of y_3 is concerned with the transfer mechanism of adaptation. As with the evolution activities in technical change, the means of adaptation are expressed by the difference between the inputs (I_t) to the mechanism and the outputs (O_t) resulting from it, as in [11], [12] and [13]:

$$y_3 \equiv Ev. \qquad [11]$$

$$y_3 = O_t / I_t \qquad [12]$$

$$y_3 = T^{a}_{t+1} / T^{a}_{t} \qquad [13]$$

In addition, the operational subsystem is affected by other components in the adaptive whole system as illustrated in [5]. Consequently, the operational subsystem of the target domain can be defined by its dependent relations within the adaptive whole system analogy. From [5], the operational subsystem is directly dependent on relations between the awareness subsystem and the monitor and control subsystem, given that the environmental conditions remain constant. This is shown in [14]:

$$y_3 = f\,(y_1, y_2) \qquad [14]$$

From this information a mathematical structure of the actual operations involved in technical change can be derived from the known activities. This is described in [15] through to [17]

$$y_3 = f\,(S), (U^{nT}_{t+1}) \qquad [15]$$

$$T^{a}_{t+1} / T^{a}_{t} = f\,(S, T^{p}_{t} - T^{a}_{t}) \qquad [16]$$

$$T^{a}_{t+1} = T^{a}_{t} \cdot f(S, T^{p}_{t} - T^{a}_{t}) \qquad [17]$$

By assuming the function, f, is able to illustrate an equivalence relation as in [18], then a mathematical structure of the operational subsystem can be defined in [19]:

$$f(S, T^p_t - T^a_t) \equiv S.(T^p_t - T^a_t) \qquad [18]$$

$$T^a_{t+1} = S.T^a_t.(T^p_t - T^a_t) \qquad [19]$$

This second stage of analogical reasoning has defined the dependent relations through the structural analogy between the adaptive whole system and the target domain of technical change. Three subsystems in the adaptive whole system of technical change are present: (i) a technical uncertainty subsystem, (ii) a technical stability subsystem and (iii) a technical adaptation system. From the mathematical structure obtained from [8], [9], [10], [13] and [15] that a conceptual model of the structure is described by figure 4.5.

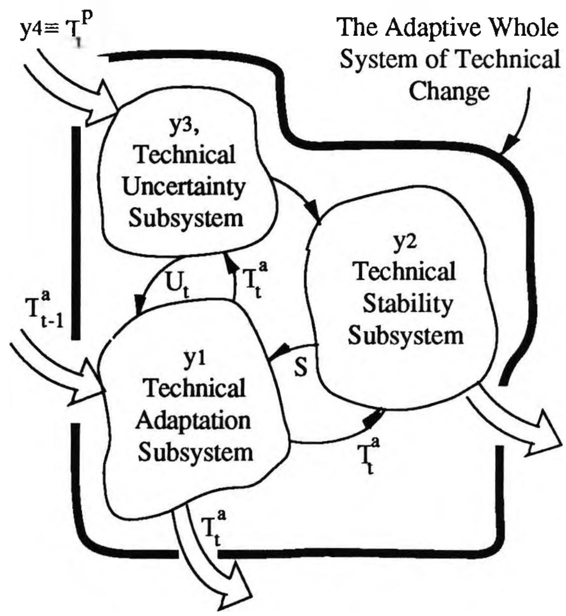


Figure 4.5 a conceptual model of the adaptive whole system structure for technical change

4.43 Analysis of the Dynamics of the Structure

Stage two of this process of analogical reasoning has provided a conceptual model of the systemic structure for technical change. The next stage proceeds with an analysis of the dynamics of the systemic structure. The aim of this is to indicate areas of isomorphism between this systemic structure and the activities of technical change. The analysis is conduced in three stages: (i) to define the mathematical structure to be tested, and associated assumptions, (ii) to simulate the behaviour of the structure and (ii) to interpret the simulation outputs obtained.

The dynamics associated with the adaptive whole system structure of technical change are reflected through the activities of the adaptation subsystem. By testing the dynamics associated with this particular subsystem, it is possible to analyse the operational behaviour of the systemic structure. By [19], the adaptation subsystem can be defined by:

$$T^{a}_{t+1} = S.T^{a}_{t}.(T^{p}_{t} - T^{a}_{t}) \qquad [19]$$

To simulate this mathematical structure of the adaptation subsystem, it is assumed that the variable T^{p}_{t}, has a hypothetical value, that is, $T^{p}_{t} = 1$, and conforms to the biological hypothesis that there is some form of limiting factor which eventually restricts the process of continual technical change. This remains for the period T_0 to T_n. Given this assumption, the structure appears as [20].

$$T^{a}_{t+1} = S.T^{a}_{t}.(1 - T^{a}_{t}) \qquad [20]$$

In addition, the simulation models the activities associated within the adaptation subsystem occur over uniform time periods, with $\Delta t = 0.1$, with the initial condition for each simulation being given as $T^{a}_{t} = 0.1$. Four simulations are carried out. Each simulation uses a different value for the stability variable (S). These are given as: (S_1= 2), (S_2= 3), (S_3= 20) and (S_4= 25). The outputs from these four simulations are presented in figure 4.6.

These outputs illustrate the dynamics of the adaptation subsystem structure. From simulations S_1 and S_2, the indication is that the dynamic behaviour of the adaptation subsystem follows an identical pattern to that of the characteristic sigmoid curve, which has traditionally been seen as the basis for describing technical changes. This identical pattern gives some indication as to the isomorphic aspects associated with the adaptive whole system structure of technical change. The difference between the two curves reflects how the value of the stability variable (S) determines the closeness of the eventual technical changes will be to its potential value T^{p}_{t}.

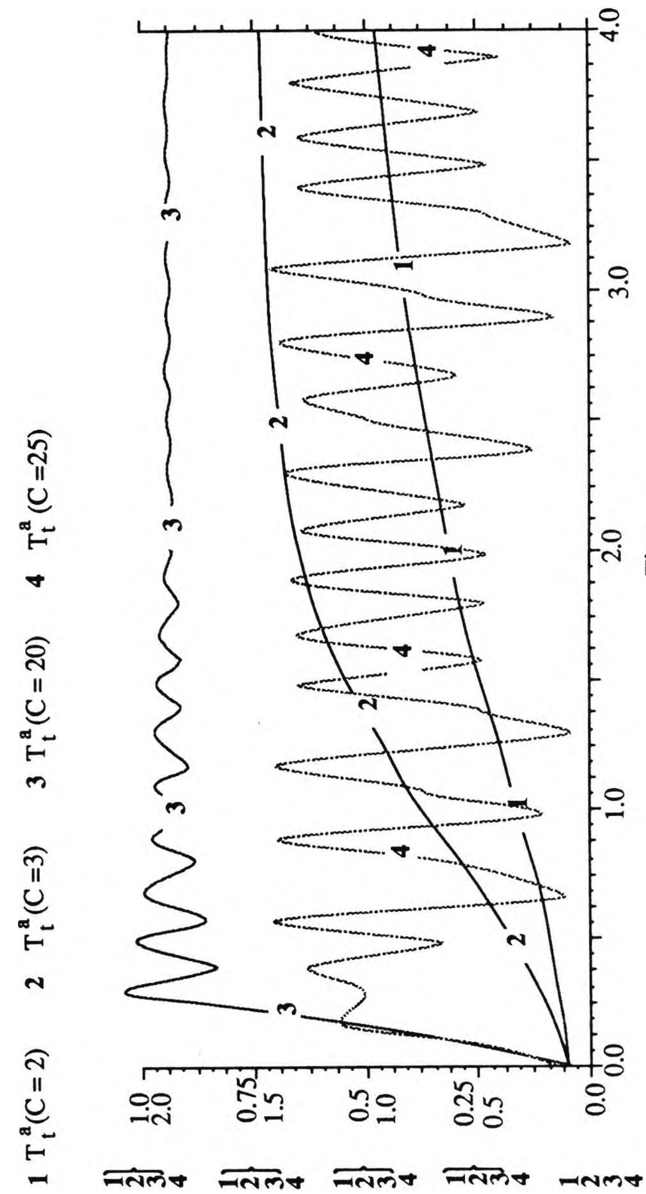


Figure 4.6 simulation results of the adaptation subsystem structure

From the simulation S_3, the dynamics of the same structure indicate a technical change pattern containing two characteristics of: (i) damped oscillation and (ii) stable oscillation. The cause of this is found in the parameter value of the stability variable (S). By increasing the value of this variable to 20, causes an unstable dynamic pattern to emerge from the structure of the adaptation subsystem.

From the final simulation, S_4, the increase in the value of the stability variable causes the structure to indicate a form of chaotic behaviour. From this it is not possible to predict the nature of any technical change simply from the systemic structure of the adaptive whole system of technical change.

Given these general outputs taken from the analysis it is possible to infer: (i) that the stability activities identified in a monitor and control subsystem define the dynamic behaviour of the adaptation subsystem in the adaptive whole system of technical change. (ii) It is not possible to predict the future state of technical changes with any degree of accuracy, this has also been verified in statements regarding technical forecasting by Gordon and Greenspan (1988). What can be achieved is to determine the most appropriate structural conditions in order to be prepared for technical change. (iii) Although the structure of the adaptive whole system and technical change does indicate some degree of isomorphism, the results obtained are not conclusive.

4.44 The System Scientific Model of Technical Change

The development of a system scientific model of technical change can be developed if the isomorphic characteristics between the adaptive whole system and technical change are generally acceptable. Whilst the known dynamic behaviour of technical change appears isomorphic with the adaptive whole system of technical change, the adaptive whole system structure provides additional information which requires a more detailed system scientific investigation. However, it is possible to generalise that the conceptual model of the adaptive whole system structure as illustrated in figure 4.5, is acceptable as a system scientific model of technical change.

4.6 Conclusions

How does a system analogy define a general structure for a new breed of technical change model? In this chapter, the role of analogy in determining the structure of a technical change model has been considered in two areas: (i) by identifying analogical ideas in diagnosing a technical change system and (ii) by illustrating the process of analogical reasoning in practice. It is from these areas that the following conclusions can be drawn.

(i) The potential for system analogies. Using de Raadt's (1988) comments on the problems of system design, it can be argued that there is an inability to carry out any systems based investigation of a new structure without some form of preconceived model by which an analysis can be made. The conclusion from this is, that without the precedence of any general model, the type of systems which are being investigated cannot be designed, they can only be managed. The implication for the system analogies is that they provide the possible preconceived information and can link design with various situations which can then be used to overcome this particular hurdle in the design stage.

(ii) The meta-theory for system analogies. Counelis (1989), constructs a meta-theory of analogy in terms of three aspects: (i) the location of the core analogical region, (ii) a set of statements constructed from the analogy and (iii) known statements regarding the target domain. From this meta-theory, the location of the core analogical region between technical change and Systems Science was defined in terms of the structural characteristics of both domains. The most appropriate system analogy was classified as the adaptive whole system, which contained particular statements regarding the structural relationships between three particular subsystems concerned with the activities of (i) awareness, (ii) operations and (iii) monitoring and control. Statements regarding the known activities of technical change were categorised into (i) evolution, (ii) stability and (iii) uncertainty.

(iii) A methodology for scientific modelling. By establishing these analogical ideas, the use of the adaptive whole system in a methodological approach to scientifically model technical change was developed. Using Beer's (1984) methodology of topological maps, this four stage process which used the analogical ideas developed in Counelis's (1989) meta-theory was adopted. The rigourous formulation using a mathematical orientation was found to illustrate the variability of technical change according to the changes to a control function. But this important insight has to be accepted in relation to a number of limitations. These include: (i) the requirement for generalisation for the technology variable, (ii) the assumption reflecting the finite nature of technical change and (iii) the use of a uniform time period in which technical change takes place.

(iv) A system scientific model of technical change. From the four stage methodology a system scientific model of technical change was produced. Based on the adaptive whole system analogy, it contains three subsystems concerned with the activities of: (i) uncertainty, (ii) stability and (iii) adaptation. Whilst this model presents a generalised systemic structure the analysis conducted on the dynamics associated with the structure indicated that (i) the stability activities act as a controlling mechanism which can cause various degree of oscillatory activity within the adaptive whole system of technical change. (ii) The unpredictability of technical change, as derived from the simulation outputs, renders any form of prediction of technical change theoretically meaningless. (iii) The isomorphism identified in the analysis did not present conclusive evidence that the generalised adaptive whole system model could accurately portray the structure of technical change.

From these conclusions, the following question is raised; whether the straight forward adaptive whole system is acceptable as a general structural model of technical change? The indication is that the problems of defining the various functional characteristics of the monitoring and control subsystem leads to an inability to help provide the appropriate structural characteristics of technical change. Further, the link between the uncertainty and monitoring and control subsystems is not defined in the adaptive whole system model of technical change. Whilst the analogical evidence suggests that the building blocks of the adaptive whole system are appropriate, a supplementary question emerges: that is, what other samples of the adaptive whole system analogy are available for a more detailed analogical investigation?

This particular question raises the issue of Beer's (1984) 'yo-yo' technique in the methodology of topological maps. This technique illustrates a means of returning from the scientific model developed through the first four stages, and reassessing the value of the analogy in terms of insight gained from the process, and proceeding with other samples from the same class of analogy.

Whilst the adaptive whole system model provides a structure with the essential activities in a process of technical change, the outputs from the simulation indicate that the step wise adaptation of the system to its environment must be rejected. Instead, the model suggests that although the real sources of change are rooted within the existing system, the equilibrium hypothesis is incorrect for technical change. The consequence of this is that the adaptive whole system description of technical change tends to derive from situations of non-equilibrium, where the inner dynamics derive new structures from their self-organisation (Jantsch, 1980). The indication is that a more detailed analogical investigation needs to be carried out to identify how self-organisation concepts within an adaptive whole system might be used to present a particular structure of technical change.

In this respect, one example within the class of adaptive whole system, which illustrates self-organisation concepts as well as providing some positive system considerations to activities of control, adaptation and awareness, is identified as the viable system. By using Beer's (1984) 'yo-yo' technique, how does the viable system analogy illustrate a more detailed structure of technical change? Chapter Five examines this question and describes how the viable system analogy can be used in a second pass through Beer's (1984) methodology of topological maps, using the viable system analogy. In addition it will be shown how the analogical process is taken away from the initial reliance on a mathematical formulation of analogical relations with its identified limitations, as provided in Chapter Four, to a more qualitative analogical process using Beer's (1984) methodology.

CHAPTER FIVE

A VIABLE SYSTEM ANALOGY FOR A CONCEPTUAL MODEL OF TECHNICAL CHANGE

5.1 Introduction

The adaptive whole system model of technical change emerged from a process of analogical reasoning which used Beer's (1984) methodology of topological maps. The use of the methodology in practice, illustrated the capacity of the adaptive whole system analogy to provide a link with the known activities of technical change. However, any general acceptance of the model was disregarded, as problems concerning the function of the stability subsystem, and its link with the adaptation and uncertainty subsystems within the model were identified.

Whilst the adaptive whole system model describes the building blocks of a structure for technical change it was indicated, in the conclusions of Chapter Four, that an additional example of the adaptive whole system analogy would generate a more acceptable system scientific model of the structure of technical change. This example was defined as, the viable system analogy. By using Beer's (1984) 'yo-yo' technique within the methodology, Chapter Five now considers how the viable system analogy can provide a more detailed model of the systemic structure of technical change.

Chapter Five is presented in three main sections: the first section discusses the 'yo-yo' technique in terms of Beer's (1984) methodology as outlined in Chapter Four. A description of the model of the viable system is given, and some examples of technical change provide the first stage of generating some additional analogical insights between the two situations. A second section describes the development of a conceptual model of technical change which uses the viable system analogy with perceptions relating to the known activities of technical change. The five subsystems, defined in the viable system analogy, are used to present the particular structural aspects of technical change. The relations between these subsystems are then used to present a conceptual description for a viable system model of technical change. A final section is used to discuss the conclusions from the approach used and the conceptual model obtained.

5.2 The 'Yo-Yo' Technique

Chapter Four constructed an adaptive whole system model of technical change, by mapping the adaptive whole system onto a situation of technical change. It is now the wish to test another example of the adaptive whole system against the situation of technical change. The 'yo-yo' technique provides the appropriate mechanism to do this. In the first pass through the methodology, the chain of similes, analogies and homomorphs are identified until the isomorph is reached, by testing insights and invariances as appropriate on the way. Through the 'yo-yo' technique, a return up the chain can be achieved by identifying another example of the analogy. This analogy can then be used on a second pass through the methodology. The process is illustrated in figure 5.1.

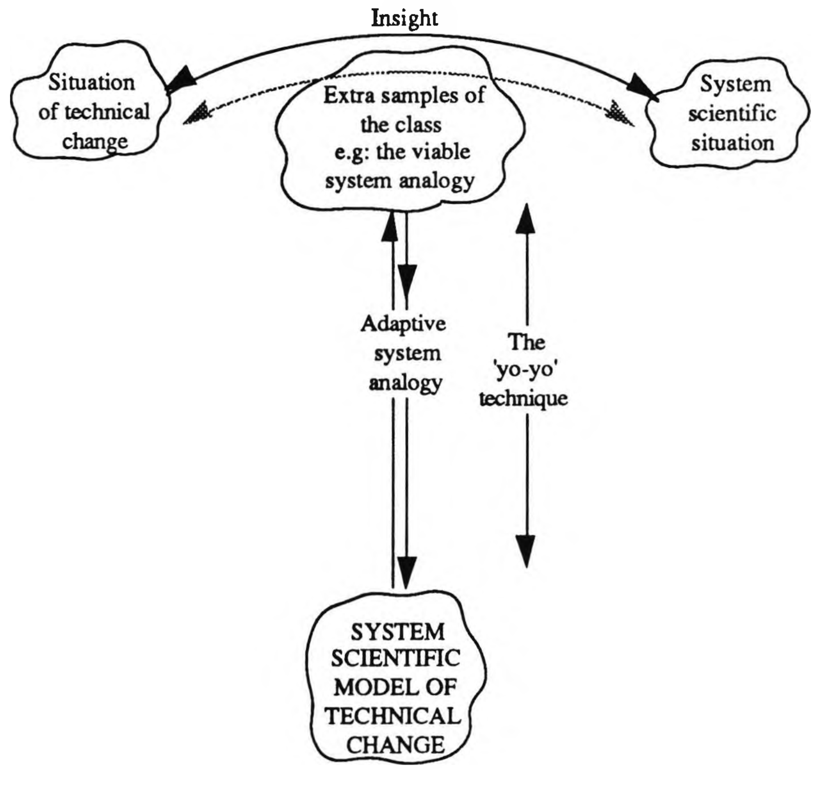


Figure 5.1 illustrating the 'yo-yo' technique

Flood (1990) identifies that the structural link between the adaptive whole system and the viable system is acceptable. In order to make a second pass through Beer's (1984) methodology, the identification of details concerning the general structural characteristics of the viable system must be made. In addition, some examples of technical change in practice are described in order to provide added expression to the similarities already identified in Chapter Four.

5.21 A Description of Viable Systems

The books and articles in which Beer's model of the viable system is described are numerous (Beer, 1979, 1981, 1984, 1985). The intention here is to briefly set out the core characteristics described in the model which forms the basis of viable systems. To this extent, the information presented below summarises the comments put forward by Jackson (1989) in describing viable systems.

Beer's general aim is to discover the laws which support the viability of systems so that it can be understood how systems are capable of independent existence. In order to achieve this Beer has embarked on a process of scientific modelling which has been used to illustrate the characteristics of viable systems. According to the model, Beer states that all viable systems possess five particular functions, defined as Systems One to Five. System One consists of a structure which is directly related to operational activities, that is, activities of implementation. System One is autonomous in its own right, this means that its parts must also consist of other viable systems whilst illustrating the five functions. This means that the structure of the viable system becomes replicated within its parts. Systems Two to Five emerge from the need support the operations of System One, and to help coordinate the changes of the whole viable system. Coordination is the principal function of System Two, creating the appropriate conditions in which the activities in System One act in harmony. System Three is used as a control function, whose ultimate responsibility lies in maintaining the internal stability of the viable system. The function of System Four, is defined by Espejo (1989) as concerned with the activities of intelligence. This is interpreted through two activities: (i) information gathering and (ii) enabling communication between other functions. System Five is concerned with the function of preparation, that is to include the activities of shaping the viable function of the system, whilst representing the necessary qualities of the whole system to a wider system which it may form a part.

Beer's model of the viable system also illustrates the information channels between the five system boundaries and as a result, these five system functions, and the dependent information relations, describe the minimum structural requirements for viable systems. A diagram of the viable system model is illustrated in figure 5.2

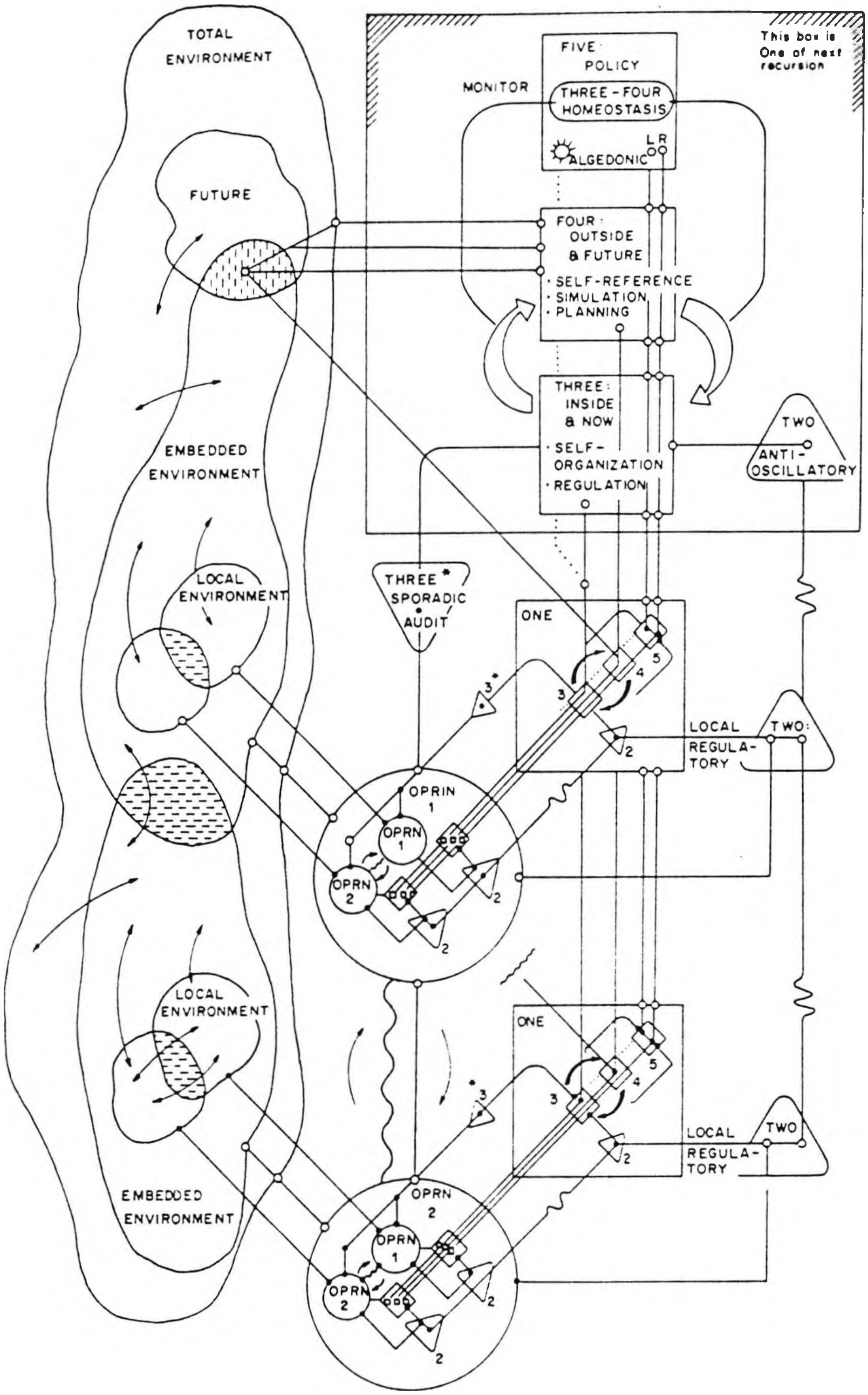


Figure 5.2 the viable system model showing recursive embedments (Beer, 1985, p. 15)

5.22 Further Examples of Technical Change in Practice

The following three examples provide some practical evidence which gives some expression to situations which exhibit changes in technology. The examples provide some additional insight into the characteristics involved in the process of technical change. The examples provide brief accounts of how the developments in laser technology, information technology and microelectronic technology provide particular expressions for technical changes; expressions which illustrate a degree of disorganisation in terms of a structure for technical change.

4.221 How Laser Technology Sharpens Production Efficiency in Manufacturing Industry

David Fishlock (Financial Times, 1987), reported in the Financial Times on November 11, 1987, that new laser technology could become the means by which entire products could be fashioned and fabricated from a variable range of non-metallic and metallic materials. The new technology was simply a higher precision tool which could be incorporated into existing manufacturing robotics. Although the new technology could provide a new form of manufacturing, technical problems concerned with connections to existing optical fibre technology in robots remained. Even so, the new laser technology could provide some industrial applications where speed was a critical concern, particularly in precision cutting operations. The implications according to the report was that technical forecasts saw this new laser technology as eventually eliminating the press shop in car body production provided that the mechanical handling could catch up with the speed of the laser technology. The simplest question of all was how this new development would impact the process of technical changes in manufacturing industry? The question prompted this rather comical response in the Financial Times (1987) seen in figure 5.3.

5.222 Competitive Advantage in Integrating New Information Technology

In 1979, the Advisory Council for Applied Research and Development highlighted the emerging field of information technology as one which could provide a sequence of logical operations on data of all kinds. These technical developments in information processing electronics, appropriate communication links and the rise of 'software' indicated a substantial rise in information technology usage, at all industrial levels. The

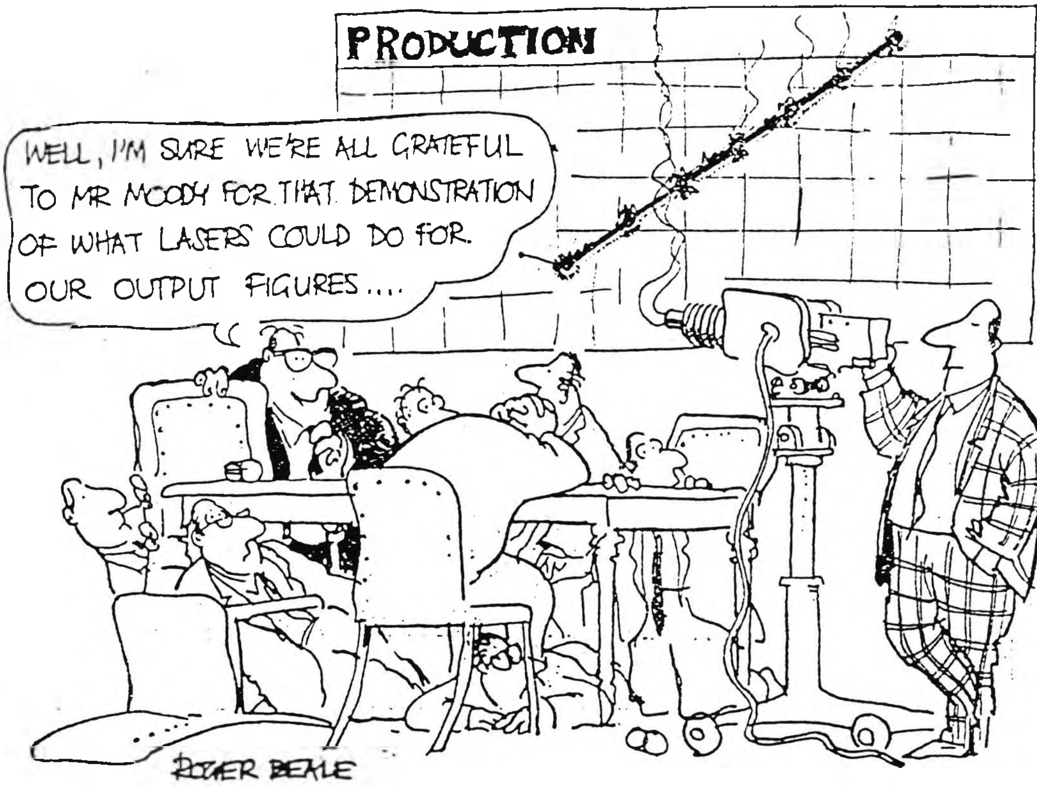


Figure 5.3 how new laser technology can improve output figures!

financial services industry were particularly strong in the adoption of this new technology. In their terms, information technology provided new ways of transacting business, with the ability to provide accurate and up to date information to employees.

Cane (1987) and Storey (1987) identified some of the implications in this type of technical change for the insurance sector. The process of technical change incorporated a number of factors such as: (i) the requirement for a sophisticated nationwide communications network, (ii) new technical operations for sifting the data as existing operations could not cope with the volume of the data, sometimes in excess of four million records and (iii) the definition of information channels. However, this technical change process was not simply a technical problem! The technical problems could be overcome through techniques such as: (i) parallel processing, (ii) relational databasing and (iii) fourth generation languages. The other related problems which directly emerged from the technical change were concerned with: (i) economic implications, (ii) business functions and (iii) skill requirements, and it was these problems which proved to be the biggest hurdles to successful technical change. The technical potential of the new technology was simple, and according to Cane (1987) it provided new views on old data, fresh insights on portfolio make-up, and an ability to 'home in' on particular points as soon as a prompt occurred. The question relating to technical change was therefore, not so much concerned with 'should we,' but more specifically, 'how should we'?

5.223 New Superconductors and the Microelectronic Industry

On March 4, 1987, the Wall Street Journal reported that scientists had discovered a compound that could eventually lead to the commercial manufacture of inexpensive 'superconductors'. The likely outcomes were said to include the feasible construction of coast-to-coast power lines, development of 'superfast' personal computers and new magnetic technology. At the time superconductors were so expensive as to render their application solely to research and limited medical applications. By the November of the same year, superconductor research was blossoming. Rippenteau (1987) reported that IBM had to invest in superconductors because it would transform computer business, with the new technology having the ability to carry 100 times more electrical current than first thought. The technical implications were potentially enormous, but all of a sudden the question was how to incorporate these new transistor like devices called superconductors with the semi-conductor technologies. How could this new technology help the microelectronics industry? And, how could this technical potential be realised?

5.23 Similarities Between Viable Systems and Technical Change

As the viable system is an example of the adaptive whole system, as expressed by Flood (1990), the structural characteristics of technical change which involve the subsystems of adaptation, uncertainty and stability still hold. However, whilst similar activities are present in the viable system analogy, there do exist other systemic characteristics of structure which can be added to the current systems model of technical change.

Whilst the operational activities are concerned with technical adaptation, the self-regulation of those activities can not be expressed adequately by the adaptive whole system structure. By introducing the viable system analogy, the activities of self-regulation and self-organisation which are integral to its structure, this offers some insight into how a more appropriate structure, utilising the activities of self-regulation and self-organisation might operate in a system of technical change.

From this information, it is proposed that the viable system analogy can offer some analogical similarity between itself and the monitor and control functions of technical change. These can be developed through the activities associated with the stability subsystem, and extended to provide additional structural links to the subsystems of adaptation and uncertainty in the adaptive whole system model of technical change. Beer (1979) maintains that the term control is that activity which facilitates the existence and operational activities of systems. It requires an ability to be aware of its operational activities and appropriate variety control mechanisms. It is from the added structural relationship between these activities that a process of self-organisation might indicate some similarity to a possible viable system of technical change.

5.3 Producing a Conceptual Model of a Viable Structure for Technical Change

It is from the assumption that the particular structure of the viable system might prove to be analogical appropriate as a structure of technical change, that a process of analogical reasoning, using Beer's (1984) methodology, is carried out for a second time. This section describes the development of a conceptual model which illustrates the structure of technical change through the viable system analogy. Whilst the general aspects associated with the adaptive whole system are incorporated, the systemic structure of technical change will emerge through the principal characteristic of viability. This is presented in two main parts: (i) through a description of a structure for technical change, defined through the activity functions of the viable system concerned with stability and (ii) by describing a structure for technical change associated with the activity characteristics for flexibility.

5.31 The Autonomics of Technical Change

The autonomic function of technical change is essentially concerned with the operational characteristics associated with the production of a dynamic cohesion between an existing technology and a new technology, that is, a process of technical adaptation. It is very much concerned with the evolutionary character expressed in Chapter Two, and is also linked to the concept of technical learning. This adaptation characteristic of technical change can be impeded, either from the external environment or from internal activities. The emergence of new technical advances, which makes obsolete existing technical products and their adaptation, is an appropriate illustration of how the cohesive force of change can be obstructed. Alternatively, some changes in existing technical developments may be required in order to introduce new application areas. If such imbalances arise in the activities of technical adaptation, then any model which is used to represent these changes must illustrate how some form of autonomic control can allow for the change, or inhibit it. The following systemic structures of Systems One to Three, identify the characteristics of the autonomic mechanisms for a viable system of technical change.

These three systems illustrate the analogical relationship between the structure of part of the viable system and technical change and additionally, they identify particular functions associated with the dependent relations in the structure. These functions are defined by Beer (1979) as algedonic, deriving from the Greek word meaning pain or pleasure. They are determined by the activities operating within the structure of these three systems. They are alerted to the disrupting effects of technical changes, and use the variety in their regulatory acts to remove any possible discomfort. Similarly, in the literature on technical change it is quite commonplace to hear the expression '*ouch this hurts* ' as a consequence of the implementation of new technology, (Keen, 1981; Buchanan and Boddy, 1984), this indicates the essential role these three systems can play in any viable system of technical change. Whilst these algedonic systems only provide a reactive service to the viable system of technical change, a System Three can introduce new technical activities, but the criteria and the awareness of possible future technical states needs additional structural requirements from outside these three systems.

5.311 Beer's System One: A Structure of Technical Adaptation

Beer's System One defines those operational elements and their dependent relations which make System One viable. It consists of three elements: (i) a localised environment, (ii) an operational (primary) activity and (iii) and a controlling activity. The similarity between the operational subsystem of the adaptive whole system, the System One of the viable system, and the adaptation subsystem of the adaptive whole system of technical change can now be considered.

The analogical link made above, implies that the structure of Beer's System One is an appropriate mechanism for a more detailed diagnosis of the structure of an adaptation subsystem found in the adaptive whole system of technical change. From this structure, defined through this analogical relationship, the adaptation of technologies operate through a rate of change in: (i) the primary activities of the System One, (ii) a possible technical expansion area, identified in through the localised environment and (iii) a control factor operating to coordinate the defined relations between the environmental and operational activities. The System One of technical adaptation can be modelled as a combination of control, transformation and catalysing activities.

Having identified the similarities between the activities of technical change and the structure of technical adaptation, a description of the elements and their dependent relations in a System One of technical adaptation can now be presented.

In Mitchum's (1987) analysis of the possible types of technology, he presents a description of the anatomy of technology. The three main anatomical models being defined as: (i) product, (ii) process and (iii) knowledge technology. Any generic changes in technology should be able to be presented in terms of the presence and organisation of these elements in each of the modes of product, process and knowledge. These generic changes which occur in one or all of the modes illustrate the primary activities involved in technical adaptation.

Whilst the transformations which take place in these primary activities lead to technical adaptations, catalytic activity is derived from the technical expansion area and defined in terms of a localised environment. This allopoietic function helps to change the characteristics of the primary activities.

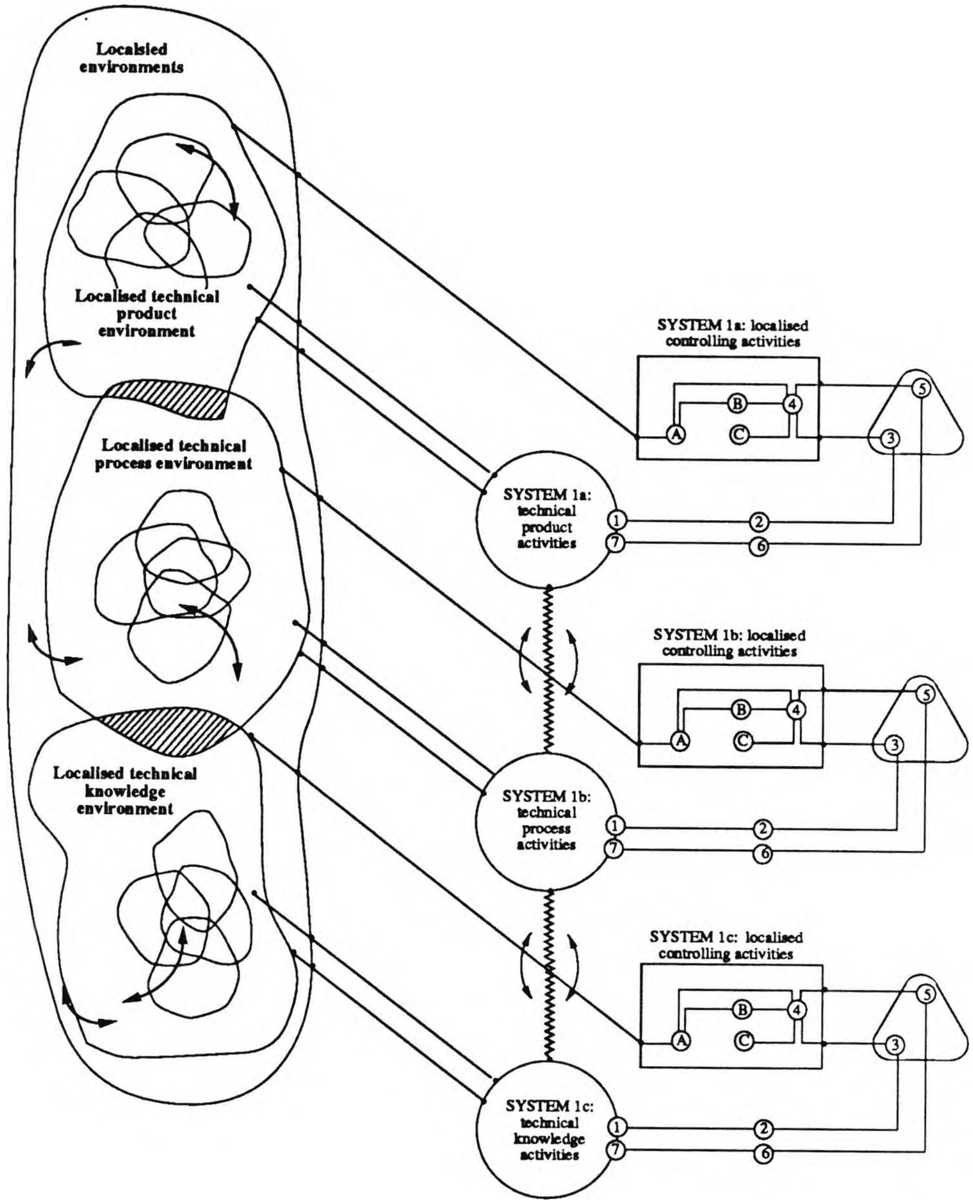
The localised environment which provides the catalytic activity for technical adaptation, with the viability of System One, is determined by its ability to enact self-regulatory powers over the primary activity. By using both negative and positive feedback controls, the indication is that the self-regulation in technical adaptation is part of System One's activity. This controlling activity operates between the localised environment and the primary activity. This activity provides a means by which technical adaptation can be compared and coordinated, through the feedback controls and through variety attenuation and amplification. Rosen (1985) states that this control activity is essential for a process of adaptation to take place. Within the localised environment and the technical modes, a process of adaptation can occur only if the changes taking place within these two elements can indicate a degree of fitness. Control provides the comparative, or monitoring function which identifies the degree of discordancy between the two activities. It is the feedback function which provides the mechanism to reduce the discordancy between the two paths. If there is no means to indicate the relationship between the paths of change in the localised environment and each technical mode, then, by inference, there can be no postulated adaptation (Rosen, 1985).

The structure of a System One of technical adaptation illustrates the dependent relations between: (i) the technical mode, (ii) a localised environment and (iii) control, with control being fundamental to the technical adaptation process. Without this activity, the primary activity and its associated localised environment would function unrestrained. The control activity provides the systemic viability which allows for an autonomous process of technical adaptation within the structure of a System One.

From this analogical comparison of System One within a viable system, and the adaptation subsystem of technical change, the structural attributes which are defined through the relations held between the elements of control, the technical mode and the localised environment present two particular implications concerning the function of technical adaptation. These are: (i) the adaptation process is dependent upon the monitor and control activity and (ii) the degree of adaptation is conditioned by the catalytic activity available through the localised technical environment and the available functions within the modal activity.

This technical adaptation system, expressed as a part of a viable technical change system, is capable of operations within a localised technical expansion area. The structure of this adaptation system defines the actual operational mechanisms which can induce technical change, and the degree to which technical adaptation occurs is dependent on the controlling activity within this structure. The control function attempts to create a dynamic cohesion between the localised technical environment and the technical mode which contributes to the degree of fitness between the two activities. From Mitchum (1987), the anatomy of technology consists of the three modes defined as: (i) technical product, (ii) technical process and (iii) technical knowledge. It is from this anatomical assumption that three System One's of technical adaptation can be defined.

An illustration of the activities associated within the System One structure is given in figure 5.4.



Key: Activities associated with the structural relations of three System Ones of technical adapatation

(1) Identifying technical mode

(2) Monitoring characteristics of technical mode

(3) Identify change characteristics of technical mode

(4) Comparison of path of change between localised environment and technical mode

(5) Coordination of model feedback for adaptation

(7) Feedback action on technical mode

(6) Selection of technical modal proposals for adaptation

(A) Monitor activities in localised environment

(B) Identify changing characteristics in localised environment

(C) Introduce comparison criteria

Figure 5.4 the structure of System One, using Mitchum's (1987) anatomy of technology

The structure of a viable system of technical change now has to consider three operational elements, each arranged in a cohesive viable system which seeks autonomous activity. Each System One attempts to perform an optimising function, but receiving technical characteristics concerning each technical mode, results in a new set of constraints on the autonomy in each System One. The implication is that the instability between the individual autonomous System One's does create a potentially damaging condition for the viable system of technical change. This oscillation occurs from the vertical interaction of these technical modes. The only means to damp this technical oscillation must be to define the anti-oscillatory mechanisms in the viable system. By deriving the relations held between System One and System Two of the viable system, an analogical discussion can be presented which illustrates the structural requirements for a anti-oscillation system in a viable system of technical change.

5.312 System Two: An Anti-Oscillation Structure in Technical Change

From the outputs of the simulation described in Section 4.43, the oscillatory characteristics in the adaptive whole system of technical change illustrated the potentially damaging impact of the osciallation on the process. Using the structure of Beer's System Two in its analogical context, it is possible to identify an appropriate anti-oscillatory structure within a viable system of technical change. Interpreting Beer's (1979) arguments, this technical oscillation would be caused by the amount of additional variety generated through the vertical interactions of the technical modes occuring in the three System One's of technical adaptation. The self-regulation which occurs within each System One is unable to cope with this added variety, as the 'horizontal' control mechanisms are not designed to cope with this level variety. The consequence is that oscillatory action amongst the activities in each System One emerges. This characteristic is not unusual. Zeigler and Reynolds (1985) discuss this problem and acknowledge the importance of generating a structure which reduces the impact of such technical characteristics. This is evident from the following extract:

> "Such [technical] evolution must necessarily be constrained by structural transformations that are feasible, in which we include such considerations as capacity to effect the change, stability of the resulting system, etc."
> (Zeigler and Reynolds, 1985, p. 309)

Beer (1979, p. 180) defines System Two as, "...the meta-system to system one". With the collection of operational elements exhausting all the basic activities within System One, what remains is either a collection of subsystems which function within the operational elements, or, is represented as meta-systemic. The activities associated with this meta-system are used whenever the operational elements are unable to initiate self-regulation. According to Aulin (1979) this structure illustrates a logical relationship. The activities of the meta-system would provide the form of intervention which helps to maintain an overall cohesiveness amongst the technical modes. If there is no intervention the possibility of oscillatory consequences within the system become a feature. This is derived from the various emergent characteristics which would result from the viable system activities.

The System Two structure derives from Beer's (1979) three concepts of: (i) requisite variety, (ii) channel capacity and (iii) transduction. Through these concepts, the structure of System Two can provide an analogical relation between anti-oscillation within a viable system and the structural characteristics which deny the instability which can emerge from the process of technical change. The structure removes oscillation resulting from the interaction of the primary activities by transducing information from the coordinating functions of system one, and initiating appropriate variety reductions to the individual systems. In these terms, System Two can analogically illustrate a service to the operational activities of technical change.

A definition for the structure of System Two is somewhat vague and elusive. In Beer's (1979, p. 189) words "...no one knows what it is," and yet it appears in many systems simply by accident, and hence, goes largely unrecognised. The essential idea behind this structure is that it only exists to dampen oscillatory or unstable behaviour, this is its ONLY function. In this sense System Two can contribute something new and important to the investigation of a viable system of technical change. Holmberg (1989) suggests that System Two offers a set of elements and relations which can damp down oscillatory action. From this interpretation, a more informed structure which removes instability from technical change can be presented.

The structure of a System Two, in the analogically proposed viable system of technical change is most appropriately described through a meta-systemic coordination mechanism. This mechanism contains the appropriate variety to initiate the means to dampen the oscillatory effects of technical modal interaction. This is carried out by controlling the coordinating variety activities in System One through the 'vertical' plane. The magnitude of this damping activity is dependent on the size of the technical variety emerging from System One. It is from this structure that the certain characteristics of technical change can be more thoroughly investigated. Figure 5.5

indicates the structural arrangement for an anti-oscillatory mechanism for the process of technical change.

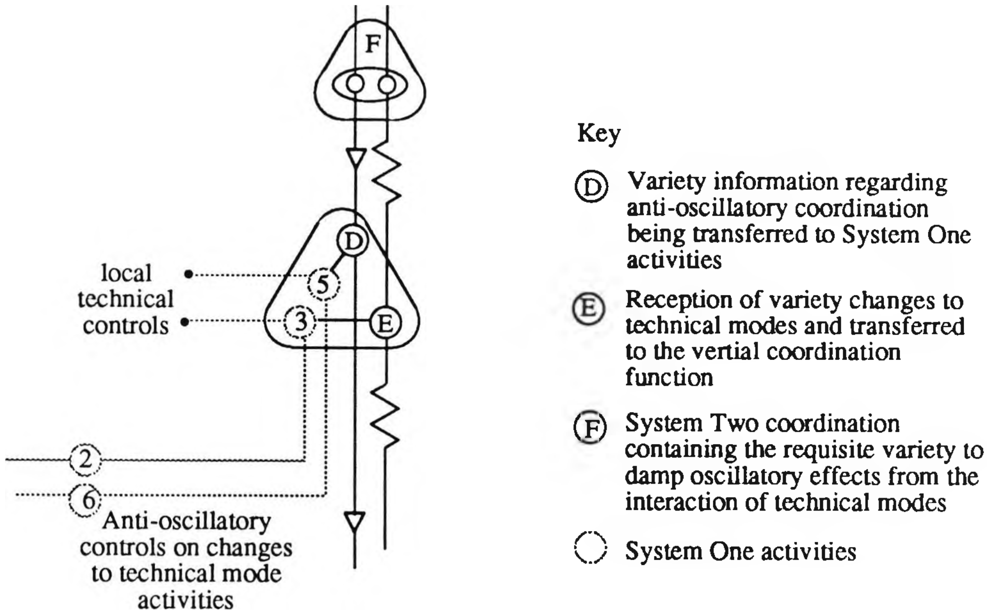


Figure 5.5 the anti-oscillatory structure of a System Two in the viable process of technical change

This structure of System Two implies that if there is more self-regulation within the activities of System One, then there is a reduced requirement for the activities of System Two to implement meta-systemic regulation. However, with a more autocratic form of self-regulation it is suggested that each System One is less likely to pursue certain innovative technical adaptations because additional technical variety is being removed from the viable system. The identification of this particular property provides a possible explanation of how and why certain technologies diffuse more rapidly in the market than other technologies.

The identity of an anti-oscillatory structure for technical change invites an opportunity to identify, and briefly discuss, the characteristics of the interactions between the technical mode which can lead to oscillation. Referring to the structure of viable systems and the process of self-regulation, Jantsch (1980), identifies that the problems of self-regulation appear as a direct result of particular interactive pressures between activities with the system. These interactions are defined as (i) complementary, (ii) competitive and (iii) contradictive.

By transferring these interactions to a technical change situation, the following statements can be made: (i) complimentary technical interaction illustrates a transition towards a reorientation of the primary activities of an existing technical style. The result is that wherever possible, the interaction of those activities does lead to a mutual stimulation, exploration and extension of other factors which can affect the autonomous nature of each System One. (ii) Competitive interaction describes the technical exchange between different modal activities which cause oscillatory changes to the adaptation process within the System One's. The effect is that certain technical activity changes will degenerate because the coordination mechanism would not possess the variety to regulate the direction of the changing activity. (iii) Contradictive interactions illustrate the possibility for the sacrifice of an individual primary activity in exchange for a new 'superordinate' activity with a new functional area. This would correspond to a replacement of the characteristics within the primary activity of a System One by a more dominant activity.

Examples of these interactions can be found in some existing models of technical change, particularly where the function of technical competition plays a more dominant role, such as: Robinson (1979, 1980), Reiganum (1979) and Pope and Hauptman (1988). Complimentary interactions can be assumed to operate in the substitution models which attempt to portray the evolutionary process of technology, such as in Sharif and Kabir (1976) and Sharif and Islam (1980). There are also the contradictive aspects of technical change, which can be derived from the general production function models first described by Schumpeter (1939).

A further implication of the System Two structure in technical change, is that it illustrates a departure from analytical approaches which concentrate on single variable technical change assessments. With a single variable technical change, the role of of the System Two is not required. This is because the process of technical change does not occur through the interactions of other System Ones. By introducing a System Two structure it is now possible to illustrate the effect of multi-technical adaptation which derives from the link between the different interactions between technical modes of a particular technology, and at a higher level of recursion, between different technologies.

Technical change does not arise solely from technical substitution, technical growth or technical superordination in the adaptation process, but from the emergence of a higher level of self-regulation. Thus, System Two in a viable system of technical change illustrates a critical need for internal damping of oscillations resulting from multi-technical adaptations.

Whilst the structure of a System Two illustrates the mechanisms for anti-oscillation, Beer (1979) states that this is not the sole meta-systemic function of the viable system. A System Three offers a structural indication of some of the other meta-systemic activities required in a viable system. A definition of the relations held between System Three and Systems One and Two, presents a further analogical extension for a viable system structure of technical change, this may illustrate other necessary activities within the structure of technical change.

5.313 System Three: Creating Synergy in Technical Change

Smuts (1926) regards the concept of evolution and adaptation as synonymous to that of holism, and the study of wholes. Smuts (1926) also assumes that the characteristic of 'wholeness' is composed of two essential ingredients: (i) a degree of individual organisation and (ii) a measure of self-direction. Although he simply regarded the living as possessing the property of wholeness, he generally believed that the natural collections of matter could also be considered as wholes, and therefore contained similar properties. With this in mind technical changes or more specifically technical adaptation could be considered as:

> "Evolution [and adaptation] is not merely a process of change, of regrouping the old into new forms: it is creative, its new forms are not merely fashioned out of old materials; it creates both new materials and new forms from the synthesis of the new with the old materials."
>
> (Smuts, 1926, p. 89)

Beer (1979) defines a System Three, in the viable system, in terms of three meta-systemic functions: (i) to coordinate the activities of System Two through a comparison between internal and external variety generation. (ii) Introducing directions over all technical modes in the System One's. (iii) Control over the interactions amongst the technical modes in relation to the activities of a total environment. This particular structure and its dependent relations provide an additional analogical link to a viable system of technical change. System Three illustrates a possible synergistic structure in technical change, where the synthesis between new and existing technical activities can be developed. The complete process of technical change can not be explained simply by the analytical reduction of technical adaptations, where the activities have been mechanically rearranged to produce these incremental changes. System Three illustrates that technical change also derives from a wider tendency to produce a creative synergy. This synergy develops from the generation of new technical structures and arrangements by integrating old and new technical activities. A System Three in a viable system of technical change provides mechanisms for this new technical possibility.

From this analogical interpretation, System Three provides the additional self-regulatory action from the extra technical variety identified in the viable system environment, and that used in the self-regulation of the Systems One and Two of technical change. This is because the actions of variety regulation in System Two are not enough to accommodate the regulation of the technical non-routine or the creative. System Three is used to cope with the activities System Two cannot deal with. While a System Three of technical change can utilise the activities of System Two, it also coordinates, controls and directs the inner relations between the technical modes and the total environmental influences. This structural arrangement determines the synergistic characters of technical change.

An interpretation of Beer's (1979) definition of synergy applied to the situation of technical change, reveals that synergistic technical change occurs when a transition from positions of high variety, within each technical mode are reduced to low variety through the type of interaction. Synergy begins at the intersect of all three technical modes. It is the function of System Three to provide the criteria for defining this intersect, by directly regulating the activities in each mode. In addition, this function is linked to the need to generate a means of self-regulation in terms of the additional technical variety identified in the total environmental context.

This not only generates the possibility of multi-technical cohesion amongst the different modes, but provides a structural foundation to introduce new technical activities into the technical modes of System One by disregarding the adaptation characteristics of System One. This is defined as the Synoptic Function of technical change. A general illustration of the relationship between System Three and other viable system function is shown in figure 5. 6.

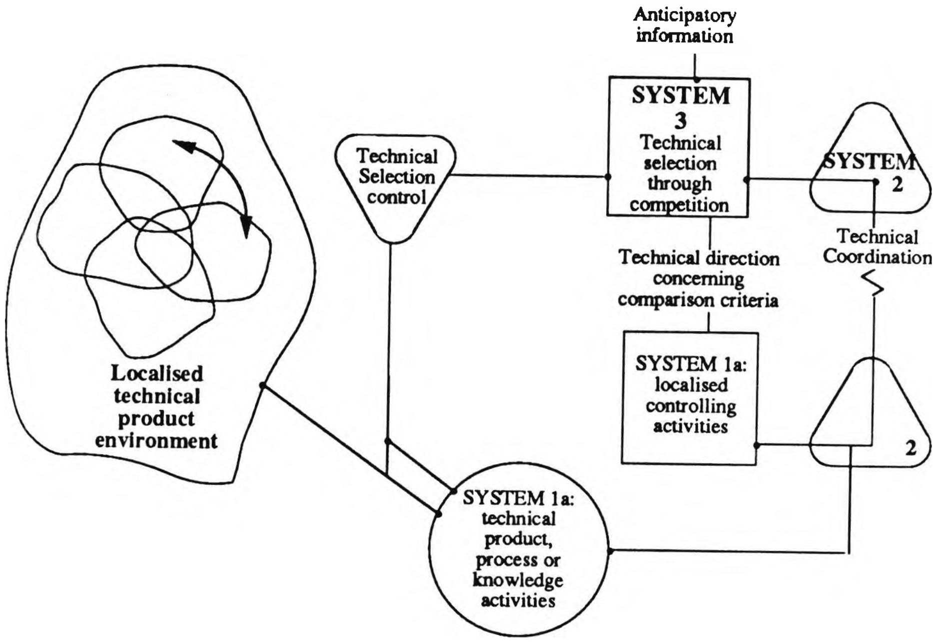


Figure 5.6 the structure of a System Three of technical change

This structure of System Three indicates that the Synoptic Function is critical to its viable nature. The function provides a link with the activities of adaptation and other aspects associated with technical change. The implication is that this Synoptic Function provides a switching activity between the adaptation activities in System One and other directives in relation to actions identified in the total environment. The switching activity is dependent upon the amount of variety regulation available to System Three. If the variety within System Three is large compared to System One, there is the possibility that the process of technical adaptation may be suppressed in an autocratic manner. The effect is to increase the possibility of heterogenetic technical styles. This stresses an important autocatalytic effect System Three plays in the viable system of technical change. This autocatalysis can be regarded as a fluctuation which forces an originally homogenetic technical style, and its movement towards a stable solution, into 'new technical heterogenetic styles' (Boyer, 1988) containing new technical properties. It is heterogenetic because the new properties identified from the total environment are allowed the freedom to compete with the existing technical styles generated by the localised environments. This characteristic can be likened to the activities of electrons which, in order to provide a higher degree of entropy produce the characteristic of 'quantum jumps'. Too little variety regulation, caused by insufficient variety in System Three, may produce an overwhelming variety in the adaptation system such that any resulting oscillatory activity might not be simply controlled by System Two because of insufficient variety within the anti-oscillation structure. Consequently, any form of synergistic technical change will be negated, causing a cessation of new technical 'jumps' to different technical styles, for example from Fordist technologies to post-Fordist technologies.

The same argument can be identified in the comments of Sahal (1979b), who states that the process of technical change can never be regarded as a homeostatic system, because the process is one of accumulation, and hence, the production of a fixed stable technical solution is always unattainable. Although the operations of technical change occur from within the primary activities, System Three provides the self-generating and self-regulating properties for accumulation of successive technical activities. In Robinson's (1979) model of technical shifts, a similar structure of a System Three is outlined where a market sector is used for technical selection between two production systems which characterise the new and the existing technical characteristics. The effect of this particular sector in the model is to introduce other characteristics of learning and the reduction of technical uncertainty.

The main consequence of this Synoptic Function operating in the System Three structure is that it has the ability to destroy or encourage the development of new superordinate technology simply by its controls of variety regulation. This can provide the viable system of technical change with the ability to generate: (i) a new form of technical advance, or (ii) technical adaptations. System Three coordinates the pluralism offered by the technical modes which define the anatomy of technology with the synergy produced by particular interactions. In addition, the self-regulation also permits higher levels of technical order to emerge through the interface between the internal activities of technical adaptation and the total environment (Jantsch, 1980).

This analogical investigation of technical change has shown some of the structural preconditions for viability. Yet, Beer (1979) states that it is not a sufficient condition. System Three identifies a structural relation between the environment and the viable system as a whole but it does not define this relation. It is, as Beer (1979) argues, an operational element of the meta-system. As System Three is concerned with directing, coordinating and controlling the operational elements of technical change, the need for a new system '...dedicated to the larger environment...' (Beer, 1979, p. 227) is required. The structural characteristics and the associated relations in a viable system of technical change are analogically defined in Section 5.32.

5.32 The Cohesive Structure for a Viable System of Technical Change

The autonomic structure defined in Systems One, Two and Three refer to that part of the process of technical change which establishes the activities of self-regulation. Although this is a condition of viability, a second condition of viability is defined by Beer (1979), in terms of the characteristics of cohesion. These characteristics are found in the meta-systemic structure of the viable system. Jantsch (1980) describes this particular systemic characteristic within a control system through the structural requirements which help to generate a means of self-organisation. The viable system contains two particular systemic structures which enable a process of self-organisation to function. Systems Four and Five identify the characteristics and dependent relations of the cohesive mechanisms to analogically complete the viable system of technical change.

5.321 System Four: External Guidance and Technical Anticipation

In order that the situation of technical change can be considered viable, it must maintain a sufficient degree of organisation for survival, that is, "...maintain a separate existence" (Beer, 1979, p. 113). Yet, technical change is not simply a question of survival but a means of progression and growth. To generate these emergent properties, a viable system of technical change must contain the structural ability for self-organisation. This can only be achieved by linking the autonomic and cohesive mechanisms in the viable system. The most appropriate means to identify the meta-systemic structure is to look beyond the autonomic mechanisms.

Technical progress is concerned with the change activities of challenge and opportunity, but coupled to these activities is the problem of technical uncertainty. Pope and Hauptman (1988) define this characteristic of technical uncertainty as the difference between the true value of an emerging technical impact, or opportunity, and the known value of that opportunity. The definition provides a useful starting point for the analogical link between the structure of a System Four of technical change and the activities carried out to reduce technical uncertainty. System Four provides an additional structural definition for dealing with this uncertainty already identified in the adaptive whole system model of technical change. It may also provide a more informed expression for the systemic viability of technical change, by integrating the activities of technical anticipation in System Four with those of activities of adaptation defined through Systems One to Three. This is a critical structure to define.

Jantsch (1980) states that the characteristic of meta-stability, that is a stability beyond which the system should maintain, emerges as a result of the limited interaction between the total environment and those activities concerned with self-regulation. The limited form of connectivity is defined in systems theory, where a decrease in entropy occurs with the result that the system not only loses its openness, but causes eventual degeneration to a point where the activities within the system can no longer be supported. If this is applied to a system of technical change, the effect would be to reduce the possibility of flexible technical change to the point where the structural characteristics, describing the autonomic function activities, create their own delays to early shifts to new technical styles. That is, where the technical adaptations remain stable far beyond the position where the technical activities were supposed to exhibit instability and subsequently enabling the introduction of new technical styles. The process of technical change must not simply rely upon the autonomic mechanisms of self-regulation, but also on an ability to maintain a process of technical progression. The analogical implications of a System Four will help define the structural requirements this meta-systemic activity.

Beer (1979) defines System Four in terms which consider the technical future, through activities which are associated with forecasting. The structure uses the amplification and attenuation of variety to define this forecasting function. The analogical similarity with technical change is easily visible, where technical change is very often viewed as the process adopted after a particular technical forecast (Ayres, 1969).

By reducing the effect of meta-stability, the central focus of a System Four structure in technical change must identify those activities involved in identifying and reducing the effects of technical uncertainties. The structure of System Four extends beyond the localised environment of System One, and incorporates an anticipatory mechanism to determine the probable effects of technical developments on the autonomic function of the viable system. Its extension beyond the localised environment can be seen, for example, by the effect that the sudden ability to use superconductivity technology at high temperatures had on in the adaptation process of semi-conductor technology (Pope and Hauptman, 1988). In addition, how the effect of fully electronic telephone exchange technology altered the technical adaptation process on semi-automatic telephone exchange technology (Clark et al., 1988).

This anticipatory mechanism not only reduces technical uncertainty, analogically it is used to regulate the variety emerging from the environment, and providing System Three with relevant information for its synoptic analysis. Yet the mechanism requires a particular systemic structure offered by a System Four. This structure provides a means to identify and monitor environmental activity and provide the catalytic evidence for technical progression, through: (i) the reduction of technical uncertainty and (ii) the removal of meta-stability in the system. It achieves this in two ways: (i) by allowing System Three to determine the primary activities with respect to future external technical activities, and (ii) through an ability to attenuate variety from the total environment by dropping a level of recursion. The reduction of technical uncertainty is accomplished by the design of variety attenuators monitoring the meta-systemic environment. Pope and Hauptman (1988, p. 14) provide two attenuating mechanisms as examples: (i) through 'search' activity and (ii) by engaging in limited 'in-house' experimental research. The channel capacities and transducers invoked in this structure provide the appropriate variety in order to generate a forecast of the implications of the current meta-systemic state which can be interpreted by the activities in the System Three structure. But the transmission of variety through attenuators and transducers is not enough without a general model of the viable system of technical change to provide the forecast to reduce the technical uncertainties regarding the total environmental implications of technical change.

The model must be constructed so as to include all the five system functions of the viable system. It is the structural link between these transducers of System Four which provide the basis for reducing this technical uncertainty. This is achieved by a third structural link between the model and the monitoring functions through a particular measures defined by the activities of the five systems. This link provides the basic structural requirements to make a comparative analysis between new variety and existing variety within the autonomic function of the viable system.

Beer (1979) explains this second function by using a biological example of the amoeba structure to describe this activity.

> "The system four of the amoeba, I submit, is amazingly ingenious. It copes with the wider environment by *dropping a level of recursion.* It divides. In this meiosis it amplifies its variety vis-a-vis the wider environment. In short the whole notion of biological evolution of survival of the fittest (with however many Neo-Darwinian refinements) involves a system four that manipulates recursiveness."
>
> (Beer, 1979, p. 229)

The link between how an amoeba functions and the description of a System Four in the viable system provides an ingenious explanation of how technical change accommodates a new and emerging technology. If a new technology is identified, and uncertainty surrounding its adoption is reduced, System Four still has to be able to cope with the added variety being introduced to the system. It can do this by having a strong regulatory mechanism within the other functions of the viable system, or it can accommodate this new variety by manipulating recursiveness. It achieves this by automatically amplifying the internal variety to accommodate the new technical variety derived from the environment. At the higher level of recursion, the two viable systems are now coordinated in such a manner as to either allow thc progression of the two technical styles, or to inhibit the activity. The whole notion of technical adaptation and the rise of new technical styles depends entirely on the activities associated with a System Four acting in this manner.

It can now be understood that a System Four of a viable system of technical change can be used to: (i) amplify internal technical variety in order to introduce new technical styles, and (ii) provide information regarding current changes to existing technical modes lying outside the local environments of System One. By operating these two activities in this System Four, it reduces the need for the viable system of technical change to drop a level of recursion every time additional technical variety emerges. System Four provides the structural cohesion between the autonomic function and other meta-systemic functions by providing System Three with the variety to: (i) coordinate, (ii) control and (iii) direct the autonomic activities reflected in: (i) technical mutation, (ii) learning and (iii) adaptation within a viable system of technical change. In addition, it has the functional capacity to drop a level of recursion in order to cope with a large increase in technical variety from the total environment and subsequently helps reduce the problem of meta-stability within the viable system. The activities associated with the structure of System Four are illustrated in figure 5.7.

From the System Four structure it is reasonable to ask the question of whether an analogical link exists between the measurements adopted in the viable system and the type of measurement which can be carried out in situations of technical change?

The dynamics of the structure of the viable system of technical change depend on the performance of the particular attributes of the technical models. In the majority of situations which express a quantification of technical change, the criteria has largely been economic: (i) cost and sales, (ii) prices, (iii) replacement costs, (iv) cash flow and (v) production capacities. In situations of technical change, the analogical similarity between the two categories of measurement defined as: (i) capacity and (ii) achievement, and the general performance criteria which is used to measure technical change has to be identified.

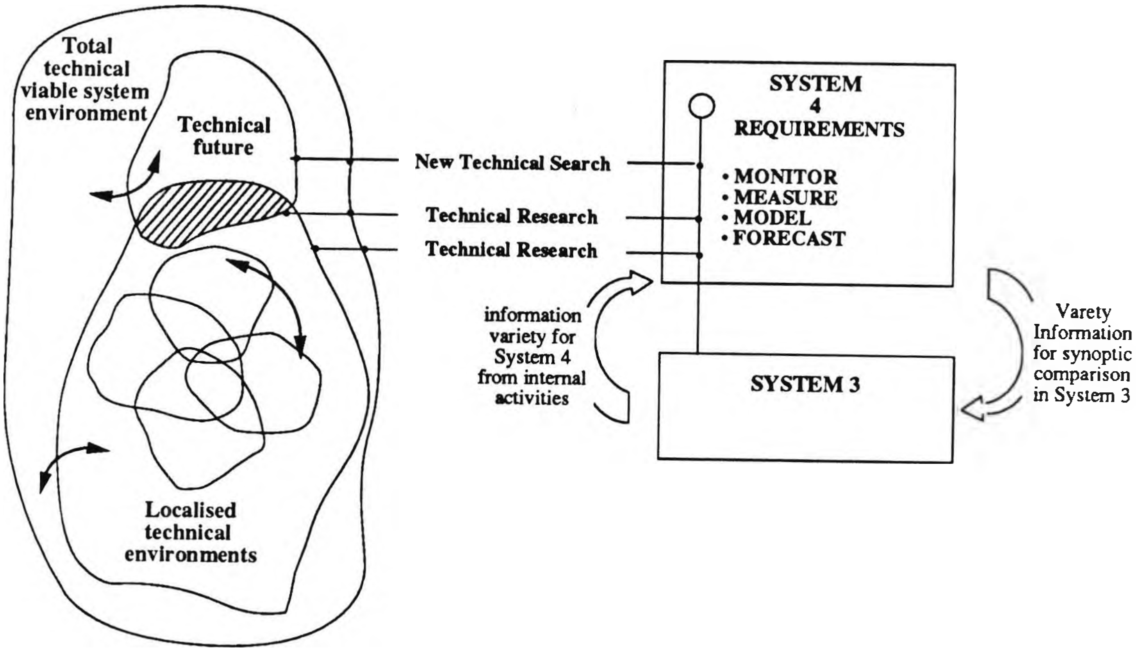


Figure 5.7 the structure of a System Four of technical change, derived analogically from viable system interpretations

From the standpoint of the viable system of technical change, the performance of each technical mode reflects both short and long term viability. The concept that successful technical change can be identified by the maximisation of profits and the diminishing rates of change to cost variables within fixed technical lifespans removes other performance factors which may be more vital to the continued viability of technical change. These are the latent capabilities of the technology which can introduce new technical activities, or be lost in the self-regulation of technical adaptations. Such capabilities cannot be reflected simply in economic performance functions.

An analogical link can be made between the measures of capacity, being strongly affiliated to cost and price variables, and achievement measures being dominated by a link to profit variables. Yet, the measures offered in the viable system assumptions provide a more comprehensive link to the performance of technical change rather than the simple value of money.

Beer (1979) describes six particular measurements which are necessary for the viable system. These are illustrated in figure 5.8. Using these six variables it is possible to introduce then into a viable system of technical change.

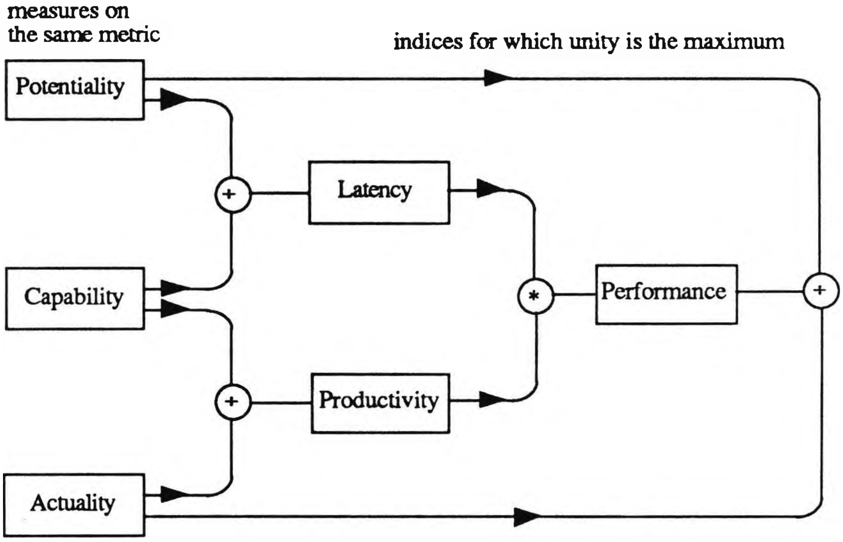


Figure 5.8 three measures of capacity generating three measures of achievement (Beer, 1979, p. 164)

Modifying Beer's (1979) definitions of these six measures, an interpretation of the value of these measures to a viable system of technical change can be determined. The achievement measures are defined as: (i) Actuality: a measure of the current change in the technical modes under existing self-organisational constraints. (ii) Capability: a measure of what is capable of being changed under self-regulatory constraints. (iii) Potentiality: a measure of the change which ought to be achieved by removing all self-organisational and self-regulatory constraints. Any one of these three measures can express a performance value of technical change, and can be used to define technical change on three different criteria. These definitions provide three sets of outlines for the interpretation of technical change using these three measurement criteria. An outline of technical change using the actuality measure indicates the adaptation of technology with its inevitable shortcomings of the situation. An outline, using the basis of a capability measure, illustrates technical change dependent on the interactions of existing technical modes. A final outline describes technical changes in terms of the autonomous potential change from the individual technical modes, illustrating the major risks and offering possible technical benefits.

Beer's (1979, p. 163) three measures of capacity, can be analogically linked to technical change simply by the nature of their definitions. These are defined as: (i)

Productivity: a ratio measure between actuality and capability. (ii) Latency: a ratio measure of capability and potentiality. (iii) Performance: a ratio measure of actuality and potentiality.

The overall measure of performance with regard to technical change illustrates the ratio of the two extremes possible. This means that whilst self-regulatory constraints may be changes in the viable system, it has no impact on the performance of technical change. The implication which can be derived from this is that the latency of the technical change is altered, because the capability measure is changing in relation to the potentiality measure. This means that new technical activities can be introduced or lost depending on the change in the self-regulatory constraints. In addition, this change in self-regulation alters the value attributed to the productivity ratio. For the performance of technical change to improve there has to be a change in at least two achievement measures.

The acceptance of these measures, as analogically appropriate and used as part of the activities in a System Four structure, illustrate how the reduction in technical uncertainty might be obtained. The measures can be applied, in general, to the performance of the viable system of technical change as a whole, or to individual activities, such as in the technical modes. By adopting these measures, it is finally possible to detect uncertainties involved in technical change. For example, a particular technical change can, and should, indicate a rise in productivity (usually identified by a rise in profits). Therefore, the technical change would be seen as successful. But the rise in productivity can simply be achieved by lowering the capability of the technical change process, through increasing self-regulatory constraints so as to destroy the latent possibility of future technical changes. This is achieved by imposing budget constraints, reduction in further research and development and the removal of technical risk. In economic measures of technical change there is no means to indicate the characteristic of technical latency. The measure adopted in a viable system of technical change whilst illustrating the rise in productivity, also indicates the deterioration in the latency ratio. These measures in the example would indicate that there was an increased possibility of future technical uncertainty with regard to technical change as a result of a forecast of the latency and performance measures and the relationship held between them.

However, the production of these measures has to involve a word of caution. This is noted in Beer, (1979)

> " However it is done, and indeed the doing may involve work study and operational research on a considerable scale, the resulting measures are simple and easy to use."
>
> (Beer, 1979, p. 166)

From these structural descriptions of a System Four in a viable system, the logical necessity to a situation of technical change has been established and is illustrated in figure 5.7. System Four provides the cohesive structure between the total environment of a viable system and the autonomic operations of technical change. But the analogical description indicates that there is a further structural component to a viable system of technical change. This fifth system is necessary to balance the variety equation between the interactions of Systems Four and Systems Three and presents a completion of the structural characteristics of the viable system.

5.332 System Five: the Structural Identity of Technical Change

System Five presents the final structural arrangement for a viable system of technical change. The function of System Five is to produce a variety balance between the activities of Systems Three and Four. Its function is like that of a lock and key mechanism, where the lock can be considered as containing those total environmental activities concerned with technical changes, and the key reflecting the available activities in the autonomic structure which can unlock those technical advances. Without some means for directing the right key to the appropriate lock there can be no System Three and System Four interaction. To introduce a new technical change within the existing operations it is necessary to select the criteria from information concerning the available 'locks', and then to imagine the key which can translate the lock into a new technical structure. This particular function is like a novelist creating a book out of words in which the existence of the book could not be apparent within the sole context of the words. This is the function of System Five, it provides an identity to the viable process of technical change, and as with Beer's (1981) model of the organisation, the characteristics of a System Five exhibit an ambiguity which appears hard to define.

The analogical link between this System Five and a situation of technical change must be reflected in the relational link between the anticipation of new technical developments and the selection of the appropriate change mechanisms. Defined in this sense, a System Five exhibits the criteria by which a balance between these functions exists. For example, the technical styles expressed by Roobeek (1987) of Fordist and post-Fordist technologies reflect two particular technical identities in which the criteria for technical change operates. If a variety of technical opportunities are inferred from the actions of System Four which cannot be absorbed in the variety of System Three, then it is necessary to depend on the sufficient variety in System Five to absorb it. If the variety regulation between Three and Four is present, System Five simply monitors that activity and technical change occurs within the criteria of the particular technical style. If System Five does not have sufficient variety then the viable system would embark on uncontrolled oscillatory movement, but this oscillatory movement could illustrate the catalytic activity for System Four to manipulate recursiveness, and create a new technical styles. The explanation can be transferred to the transition of the Fordist to post-Fordist technical styles in the manufacturing industry, where the control problems and instabilities observed provided the basis for the new post-Fordist technical style. In this way the manipulation of recursiveness creates the changing criteria in which System Five functions, where the 'key' could be found which unlocked the potential of post-Fordist technologies. The structural association of the System Five containing aspects of a technical identity is given in figure 5.9.

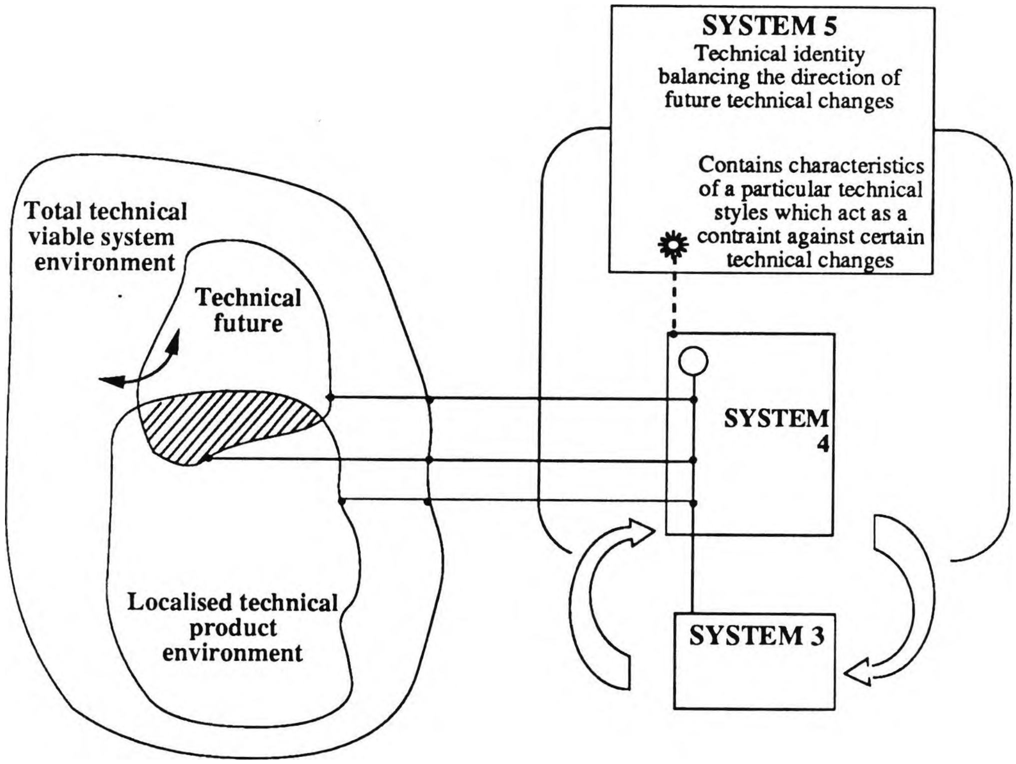


Figure 5.9 the structural arrangement of System Five and its dependent relations in a viable system of technical change

This presents the final function of a viable system of technical change, absorbing the residual variety from the interactions of Systems Three and Four. It reveals a very important implication which elucidates the complete structural viability to technical change. In the proceeding section the analogical similarities identified through the five system functions and the situation of technical change are drawn upon to illustrate a conceptual model of a viable system of technical change.

5.33 A Conceptual Model of a Viable System of Technical Change

The conceptual model which describes the viability of a systemic structure of technical change, is presented as a homomorphic map. The basis structure of a viable system of technical change can be analogically expressed in the form of the diagram in figure 5.10 and abbreviates the dense account of the structure expressed in Sections 5.31 and 5.32. The conceptual model presents an analogical correspondence between the viable system structure and that of technical change. The conceptual model contains two kinds technical change activity: (i) Systems One, Two and Three describe the self-regulatory action, and (ii) Systems Four and Five are self-organisational activities.

System One provides the mechanisms which illustrate the primary activities involved in technical change expressed as a characteristic of technical adaptation. System Two illustrates the coordination mechanism which damps the oscillatory effects caused by the interaction of the primary activities. System Three involves three functions of technical change: (i) coordination, using the activities of System Two, (ii) direction and (iii) control, to create conditions by which technical change can occur in terms of the total environment of the viable system. System Four is structurally related to System Three, and provides information concerning the current state of technical changes and a forecast of the implications derived from environmental activity. It also contains the ability to manipulate recursiveness. Finally, System Five is structured in a monitoring role between Systems Four and Three, and is used to regulate the residual variety emerging from the interaction of Systems Four and Three.

This conceptual model illustrates the applicability of the viable system as a systemic structure of technical change. It shows that by using the viable system in its analogical context it has been able to answer the structural and functional unknowns concerning technical change. Hence, assuming that the description of the viable system is given as a structural precedent; an explanation of these unknowns of technical change can be answered like one answers questions concerning Hamlet by way of knowledge about Macbeth.

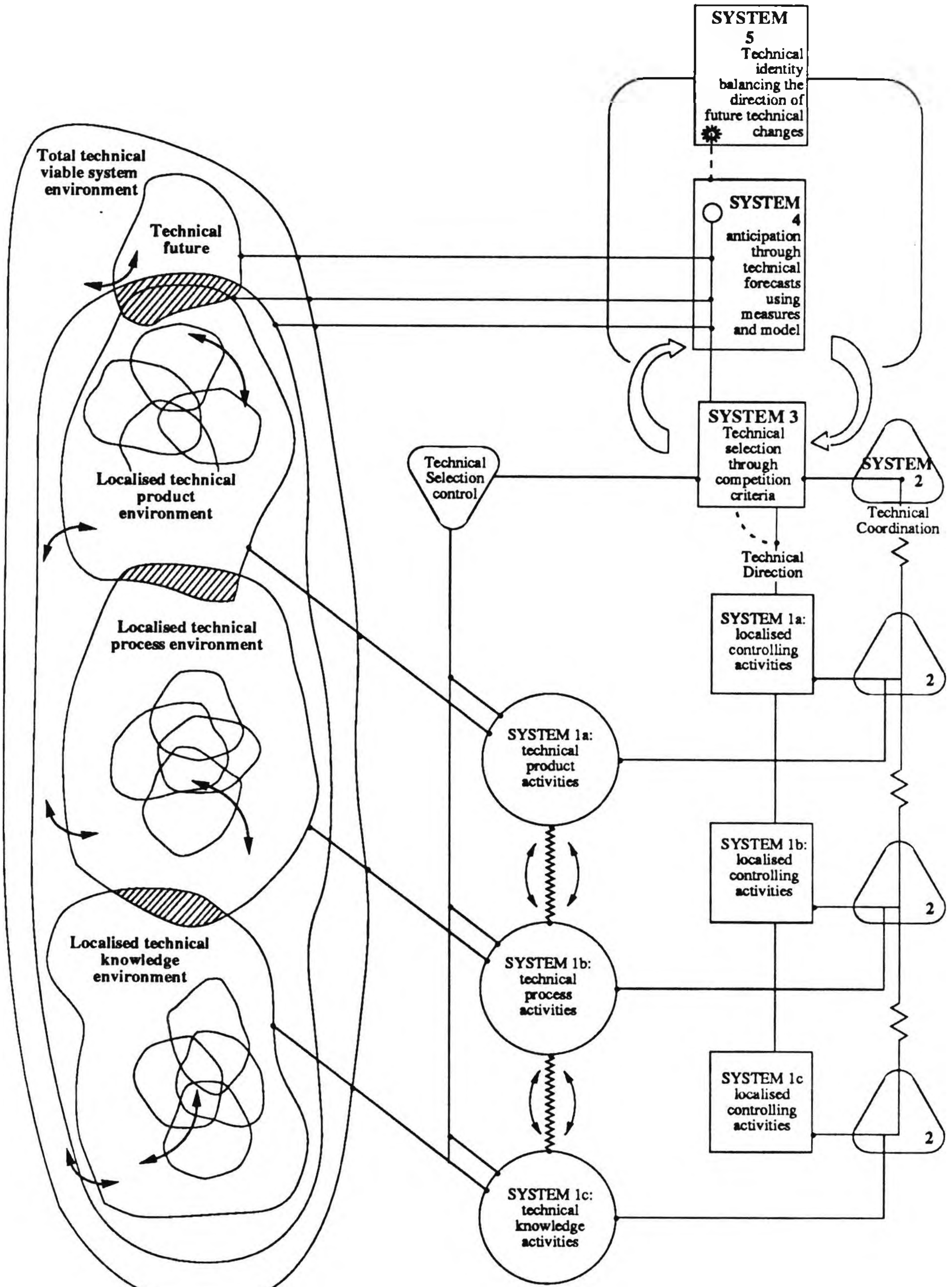


Figure 5.10 a conceptual model of a viable system of technical change

5.4 Conclusions

What then has been learned about how the viable system analogy can provide a more detailed model of the systemic structure of technical change? This question has been considered in two particular areas: (i) in the identity of similarities between viable systems and technical change and (ii) in the production of a conceptual model of a viable systemic structure of technical change, developed through a detailed analysis of the five system functions of the viable system. The conclusions obtained from these considerations are:

(i) The methodology in action. Beer's (1984) methodology of topological maps provides the process by which the analogical relationship between the structural descriptions of the viable system can be determined. The effect of the 'yo-yo' technique in this methodology has created the conditions necessary for a second exploratory investigation of technical change which has resulted in an analogical homomorphism between the structure of technical change and the viable system.

(ii) Similarities between technical change, the adaptive whole system and the viable system. Similarities between three particular structural characteristics associated with: (i) operational, (ii) controlling and (ii) identification functions were identified. Whilst the structural similarity between technical change and the adaptive whole system had been considered in Chapter Four, the structural characteristics and their dependent relations of the viable system provided an opportunity to explain, in more detail, the dynamics and control mechanisms through a more specific example of an adaptive whole system of technical change.

(iii) The structure of a viable system of technical change. The viable system analogy provided a more detailed description of the systemic structure of technical change. In particular a detailed structure operating between the operation, monitoring and control and awareness functions, revealed a process of technical change operating in a system which includes a structure surrounding five specific systemic functions.

The analogical link between the activities of a System One and technical change were identified by the generic changes which operate on the modal characteristics of technology, as defined by Mitchum (1987). These were identified as: (i) technical product, (ii) technical process and (iii) technical knowledge activities. The change in each activity was structurally related to other activities which monitored and controlled the process of change.

The structural necessity for System Two is reflected the assumed oscillatory implication of three System One's operating autonomously, whilst interacting with the other technical modes. The conclusion drawn from this was that having established that a viable system of technical change consisted of three System One's there was necessarily a structural requirement to provide an anti-oscillatory mechanism. The analogical link was identified by the resemblance of oscillatory dynamics identified in the simulation results in Section 4.43.

A System Three of technical change was determined by the analogical association with the generation of technical change as opposed to technical adaptation. System Three offers a structural explanation of how it is possible to coordinate, control and direct the primary activity in a System One, directly. The implication of this structure, is that based on a total environmental consideration a System Three provides the necessary activities to select appropriate technical changes in relation to the overall system requirements of technical change.

The Systems One, Two and Three provide the detailed structure necessary to illustrate the system activities associated with self-regulation. But rather than simply maintain a process of technical change, the emergent property of a systemic process of technical change can be regarded in terms of technical progression. Such a characteristic according to Beer (1979) requires self-organisational activities and an appropriate structure. A System Four of technical change links the activities required to forecast the necessary changes for technical progression and in doing so, reduce the effect of technical uncertainties. The ability to monitor the environment, and to transduce variety into the controlling function of System Three provide technical change with a structure to illustrate the activities of self-organisational. In addition, the analogical similarity offered between measures in the viable system and technical change, illustrate how the particular measurement definitions within a viable system of technical change can offer far more insight than existing financial measurements in situations of technical change.

The analogical link between a System Five and technical change was defined in terms of the final regulatory mechanism which conditions technical change to particular styles such as: (i) Fordist technology or (ii) post-Fordist technology. System Five provides a structure which regulates the residual variety between the interactions of Systems Three and Four. However, if the variety is so great in the environment, System Four can manipulate recursiveness to generate a new viable system of technical change.

This provides the mechanism which helps the transition from Fordist to the post-Fordist technical changes.

(iv) A conceptual model. The structural relations amongst the five system structures and their associated functions provide a complete systemic structure for technical change. Using these similarities between the five systems and technical change a conceptual model of a viable system of technical change was constructed. The effect of the viable system analogy has been to provide this detailed structure through the use of Beer's methodology and in particular through the use of the 'yo-yo' technique.

(v) The viable system model of technical change provides an illustration of the necessary mechanisms required for the effective control of the technical change process. It extends beyond the adaptive whole system model of technical change by introducing the structural aspects of control in relation to technical change. This generates (a) a model by which a firm may make the necessary preparations for technical instability and, (b) an illustration of the particular types of control mechanism required to reduce the possibility of oscillation as identified in the adaptive whole system model, and identified from the simulation results in Chapter Four.

The viable system of technical change has been able to provide a more detailed systemic structure of technical change in three particular ways: (a) as a particular example of the adaptive whole system, defined by the 'yo-yo' technique, (b) through the detailed structural descriptions of the five systems of the viable system, and their analogical link to technical change through the methodological approach adopted, and (c) through the creation of a conceptual model of a viable system of technical change which illustrates the necessary control mechanisms.

In the next stage of the methodology the process of rigourous formulation must be considered. The particular question this raises is, whether the viable system model of technical change is a comprehensive system scientific model for these purposes? In order to consider such a question, the hypothesis that the viable system model is a comprehensive system scientific model, must be tested rigourously. In Chapters Six and Seven an evaluation process in conducted on the conceptual model of the viable system of technical change. This is used to give both a theoretical and practical evaluation of the conceptual model as presented in this Chapter.

PART THREE

CHAPTER SIX

EVALUATING VIABLE SYSTEMS OF TECHNICAL CHANGE

6.1 Introduction

Chapter Five discussed the analogical association between a structure of viable systems and technical change. This analogical relationship resulted in a conceptual model of technical change which resembled the structure of the viable system. Whether this viable system model is a comprehensive system scientific model of technical change will be examined in Part Three. The main theme of Chapter Six is to present a comprehensive evaluation of the structure expressed in the viable system model of technical change by using certain theoretical examples. The evaluation process used will determine the significance of the viable system model, through these examples, in order to provide the basis for establishing whether the model does actually present a comprehensive system scientific model.

Dimond and Ellis (1989a) discuss the various examples of technical change based on theoretical evidence, and classify them into five principal areas: (i) economic, (ii) engineering, (iii) technical, (iv) human activity and (v) political. The most common of these categories are: (i) economic and (ii) human activity. Nass and Mason (1990, p. 46) also indicate that the two most common forms of analysis of computer technology changes are: (i) actor-centred and (ii) object-centred approaches.

Chapter Six will assess the viable system model of technical change in order to determine whether the model presents a comprehensive system scientific model. This will be achieved by evaluating the model in relation to two theoretical examples from: (i) economic and (ii) human activity descriptions. This chapter is divided into four main sections. The first section describes the general evaluation process to be carried out on the two theoretic examples. The second and third sections describe the activities of the evaluation between the viable system model of technical change and the two examples used. The fourth section presents the conclusions drawn from the evaluations carried out on the two examples.

6.2 The Evaluation Process

Chapter five concluded with the hypothesis that the viable system model of technical change was acceptable as a system scientific model in this new and untested area of application. In this chapter, the evaluation process is used to cxamine this hypothesis. To achieve this, the evaluation process of the viable system model of technical change must extend beyond the system and cybernetic assumptions used in the description of the model, and test the hypothesis using other examples of technical change, identified by both economic and social descriptions.

Jackson (1989) states that in any evaluation process there is a necessity to ensure that the activities chosen for the purpose of evaluation must be reasonable and fair in relation to both the model and the domain of application. In respect of this, Summers (1990) states that any evaluation process should contain three particular stages: (i) a needs evaluation, (ii) a formative evaluation and (iii) a summative evaluation. With this in mind, the stages in the evaluation process are made in relation to its significance to the premises that underpin the theoretical evidence of technical change and in relation to the purposes for which the evidence is utilised.

The needs evaluation is used to appraise the potential use of the viable system model as a structure of technical change in relation to the needs identified by each theoretically based example. The second formative stage in the evaluation process, assesses the structure identified in the viable system model of technical change relative to the characteristics present in each example. This is to be achieved by using criteria based on the five viable system functions, and will be used to identify structural areas of similarity and dissimilarity. The summative evaluation makes a comparative assessment between the structural character of the viable system model of technical change with known types of technical change identified within each example. With these aspects of the evaluation process completed, additional findings are presented from a meta-evaluation from the three stages used in each example and are presented in the conclusions (Summers, 1990). This is used to describe the similarities present within both examples using the viable system model of technical change.

Figure 6.1 outlines this evaluation process which is to be conducted on the viable system model of technical change by examining the two areas of economic and human activity descriptions of technical change.

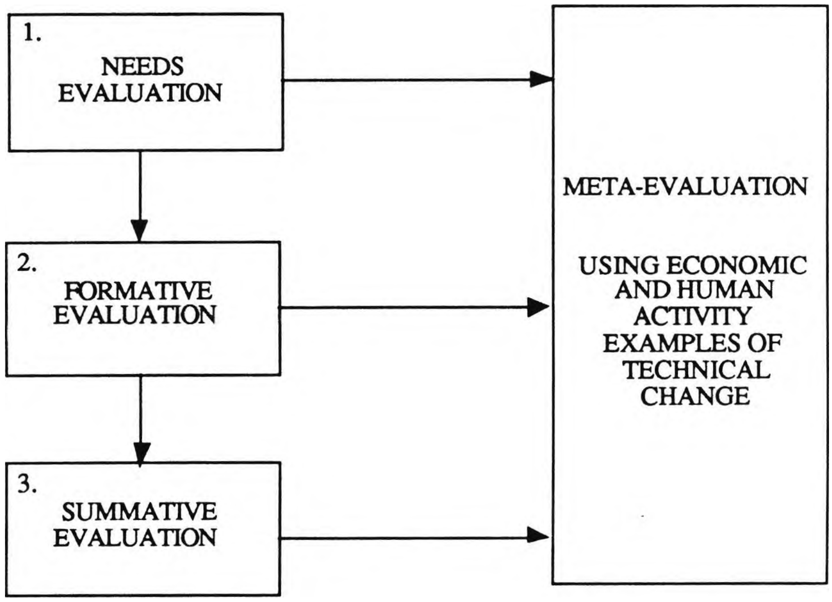


Figure 6.1 evaluation approach used to assess the viable system model of technical change (Summers 1990)

6.3 Economic Descriptions of Technical Change

For many years economists have shown varying degrees of concern about the way in which economic interpretations have tended to relegate technical changes to the fringes of an analysis of economic growth or to the basic idea of the residual factor. Indeed these features are discussed in Chapter Two. Since the works of Schumpeter (1928 and 1939), many economists have tried to follow in his path, and attempted to restore an explanation of technical changes relative to other economic aspects, whilst keeping within the main theme of a production function. Technical change is a part of economic literature since economists assume that technical change affects all aspects of economic phenomena. This ranges from, the optimistic to the pessimistic implications of technical change, to descriptions which regard technical change as an inevitable and uncontrollable process, to those who assume that the process can be planned and regulated (Heertje, 1977). By using economic descriptions of technical change, the diversity of its treatment helps to present a detailed description as to the variable nature of technical change and creates a more extensive evaluation procedure.

The evaluation process which compares these economic descriptions with the viable system model of technical change is presented below. It details the three assessment stages and presents a summary of the findings.

6.31 The Needs Evaluation

This needs evaluation considers the applicability of the viable system model of technical change to the economic descriptions of technical change. Dosi, Freeman, Nelson, Silverberg and Soete (1988) show that there is an identifiable need for restoring technical change to the centre stage in the explanation of inter-firm competition, economic development and business cycles. Indeed the work of Dosi, et al. (1988) grew out of a growing dissatisfaction with the way technical change continued to be treated in mainstream economics. The needs identified in Dosi et al. (1988) in economic descriptions of technical change were to bring together a coherent framework which could sketch out common elements, identify the economic role of technical change and the effect of technical change on the structural configurations of economic systems.

The viable system model of technical change takes appropriate steps in presenting an alternative coherent framework, and one which focuses on a structure of technical change. By adopting economic based variables within the viable systems construct, the model of technical change provides one possible means of presenting a coherent framework which does identify essential elements, whilst illustrating the economic behaviour associated with technical change.

The viable system model of technical change does fill a particular need, as expressed in the economic descriptions of technical change and identified by Dosi et al. (1988). To assess the significance with which the viable system model can fill this need in economic descriptions, the second stage of a formative evaluation considers the structure and functions expressed in the viable system model with those activities explained in current economic descriptions.

6.32 A Formative Evaluation

The formative evaluation uses criteria through which an assessment of the structure and functions expressed in the viable system model of technical change can be made to fit those activities currently described through economic interpretations of technical change. The criteria used are based on the five system functions and their dependent relations. Each particular system is assessed in terms of how economic descriptions can be reflected in the activities, structure and relations in each system.

6.321 System One and the Economics of Technical Adaptation

The basis of many economic descriptions concerning technical adaptation, principally focus on the works of Schumpeter (1928 and 1939) and on other neoclassical economists. The descriptions provide a linkage between consumer prices with labour and other costs, and the concept of technical change. This may have been appropriate for explanations concerning the Fordist technologies, but these concepts used by Schumpeter appear far too simplistic as an explanatory foundation for the nature of post-Fordist technical changes. For this formative evaluation, the work of Dosi et al. (1988) is used as the basis of current economic thought regarding the economic nature of technical change, and in particular technical adaptation.

The criteria used to evaluate the applicability of the functions and structural relations of a System One, leads to a consideration of two areas: (i) the primary activities of change, that is, the anatomical modes of technology as defined through economic descriptions and (ii) the local controls used to regulate the changes. These two areas used, assess the structural cohesion of an economic system of technical adaptation.

By using the first criteria, the viable systems description of the anatomical modes of technology provides a consideration in terms of technical product, process and knowledge variables. In the comprehensive account of economic theories to technical change, Dosi et al. (1988) identify three particular economic characteristics which are linked to an explanation of technical adaptation. The changes to a technical product, are seen through particular changes in output characteristics, as observed from changes in: (i) a manufacturing situation, (ii) demand (ii) consumer behaviour patterns.

Changes in these general output distributions present a coherent means of identifying and analysing the economic consequences of the adaptation of a new technical product. Technical adaptation is generally considered by economists as a basis for economic growth, with the catalysts for adaptation being provided by the utility of investment levels.

The rate of change of technical process adaptation is reflected in economic terms by the changes to investment levels in new technologies.

The final technical mode which is expressed within the economic system is given by the relationship held between technical changes and innovation. In economic terms, this relation is viewed through economic incentives for new technical adaptations, and is usually identified with the emergence of economic scarcities within a firm or society. By identifying the changes in the economic cost of: (i) product quality, (ii) the energy costs in the technical process and (iii) circulating capital changes, these values are associated with incentives to innovate and present adaptations to existing technical knowledge in order to reduce such scarcity values.

These economic descriptions represent the actual activities through which technical adaptations occur. That is, economic interpretations, expressed by Dosi et al. (1988), can be considered in terms of changes to three main activities: (i) output characteristics, (ii) research and development costs and (iii) technical investment figures. Within these activities the degree of adaptation is reflected through a number of variables which range from an analysis of changes in production capacities, to technical sector investments, and to the changes in relative prices of energy relative to technical adaptations. Figure 6.2 illustrates the relationship between these economic variables and the technical modes as expressed in a viable system model of technical change.

The Antomical Modes of Technology Described through Economic Characteristics	Detailed Characteristics as Defined in Dosi et al. (1988)
Investment	Sectoral investments Investment propensities Profit rates Productivity values
Output distributions	Income distribution Distribution of demand Patterns of industrial conflict Wage growth Unemployment rates Price variations
Economic incentives for technical adaptation	Labour scarcity Energy scarcity Fixed capital scarcity Circulating capital scarcity Quality problems Relative labour/machine prices Relative emergy/machine prices

Figure 6.2 details of the economic characteristics, as defined through the technical modes in a System One

The second of the two criteria used to assess the link between economic descriptions and a viable system model of technical change, describes the possible relationship between the identity and applicability of certain economic constraints being used as local regulators of System One. The definition of these controls used in this economic descriptions of technical adaptation does rely upon the financial constraint as the principal mechanism for regulation. Dosi et al. (1988) identify three types of economic constraint as: (i) economic resource allocation, (ii) budget control and (iii) technical investment criteria. It is the characteristics of these controllers which effect the economic associations between technical adaptations and, in terms defined by Pelikan (1988) the economic rules of allocation.

The structure of System One indicates that the regulation of the technical modes can be exercised through the economic resource allocation constraints. This regulation is derived by conditioning the output distributions and determine certain technical adaptations. Cohen and Halperin (1986) provide an excellent example of this type of technical change control on economic values, and state that a firm would never switch to a higher variable cost technology if the mean value of demand was rising. Switching from a lower variable cost technology would be dependent on several aspects which include: (i) the probability distribution of demand, (ii) the relationship of a firm's selling price to variable costs and (iii) the relationship between fixed costs and a contribution investment margin.

This identifiable link between changes in output distributions and resource allocation provides a structural basis for a System One of technical change. It defines the first economic System One of technical change, where a structure between the controlling activities classed in terms of: (i) cost adjustments in energy, (ii) labour, (iii) wage and (iv) price factors, are linked to the main activities which describe the economics of technical change. These controls can be used to effect the degree of change in for example: (i) wage growth and (ii) production capacities, and this can be carried through into the economic description of technical adaptation.

The second regulator, which is currently described through economic interpretations of technical change, can be generally defined through the characteristics of budgetary constraints. By examining the structure of System One, this regulatory mechanism is structurally linked to the activities of research and development. This structural definition is similar to the budgetary controls applied in Pope and Hauptman's (1988) model, where limitations on the cost of research and in house technical experimentation control the adaptive activities on technologies involved in the reduction of economic scarcities. Within this context the regulatory activity is classified simply as a short term control function over technical opportunities, with the control being generated from an expected change in profits as a result of learning from one or more innovative activity. This is achieved by direct additions to, or withdrawal from, finances aimed at specific capital intensive areas of new technology associated with the areas of economic scarcity.

Whilst current economic descriptions do not present any firm evidence to support a structured link between investment constraint and any economic description of technical adaptation, the viable system model defines the structural existence of such a link. It is clear that investment constraints are related to an estimated value of profitability from the process of technical change, and that the technical rate of economic return is a characteristic of an important regulator to technical adaptations. The regulatory constraints can be implemented through value changes in: (i) technical cash flows, (ii) discounting factors, (iii) sinking funds and (iv) the technical internal rate of return. The effect is an alteration in the tendency towards technical investment, and as defined by Dosi et al. (1988), refers to technical adaptation.

The use of the two structural characteristics in a System One of the viable system of technical change as criteria by which an assessment of current economic description of technical change are made, presents two implications. These are: (i) that there is current economic evidence of technical change which supports, to a limited extent, the structural assumptions used within an economic System One of technical change, and (ii) where there is no existing framework to establish how and why the rate of changes to technical investment, output and research and development, the activities associated with System One present a structure by which a limited examination of technical change can take place.

To evaluate a more detailed structure, a System Two is assessed in the following section with regard to current economic interpretations of technical change.

6.322 Economic Instability in Technical Change

In addition to the direct regulation of the technical modes, defined through economic descriptions operating within a System One structure, Robinson (1979) concludes that the interaction between the activities of: (i) output demand, (ii) production capacities, (iii) technical learning and (iv) relative prices, would indicate that the System One structure does not illustrate the complete structural framework for economic interpretations. The implications are that changes in these anatomical modes have an indirect influence on each other which may not be fully controlled through local regulation.

The criteria used to evaluate the economic descriptions of the interaction amongst these technical modes with the structural framework offered by the viable system model of technical change, are based on the function of System Two. This particular system is structured so as to reduce the oscillatory effects created in System One's. As a result, the criteria used in this formative evaluation assesses whether the existence of this structure is currently evident in economic descriptions. This criteria is defined by: (i) identifying the economic nature of technical instability and (ii) making reference to any economic explanations of why such instability occurs in the process of technical change.

A consequence of the direct interactions of these anatomical modes, as described through economic interpretations, is concluded by Robinson (1979), to indicate that such interactive associations create conditions of instability which need to be controlled. The evidence presented by Robinson (1979 and 1980) is qualitatively reaffirmed by Dosi et al (1988) and, in particular, by Silverberg (1988). It is this characteristic of technical instability which leads to what can be regarded as:

> "... localised and irreversible forms of technical progress [which] yield (i) non-productibility of equilibria, (ii) inflexibility (random walks having absorbing barriers); (iii) non-erodicity (the past is not forgotten and strong hysteresis effects emerge); and (iv) potential inefficiency (a particular equilibrium or, dynamically, a particular path may be inferior in terms of some welfare measure but the systems may still be locked into it."
>
> (Dosi et al. 1988, p. 16)

The structure of System Two indicates that the source of technical instability emerges from the intersects of these technical modes operating in System One. This presents a particular indication concerning how technical instability emerges within the process of technical change.

Through economic descriptions of technical change, the types of instability which are identified by Roobeek (1987) and Lundvall (1988) as: (i) non-productive technical changes, (ii) technical saturation and (iii) technical inefficiencies.

Non-productive technical changes creates an instability where changes in investment levels for new technical activities, and the desire to reduce particular economic scarcities, produces new technologies which have developed either: (i) none or, (ii) little economic demand which could not be sustained. Roobeek (1987) states that this powerful under utilisation of new technology not only effects subsequent adaptations but also puts additional pressure on the economic relationship between technical advances and economic growth.

The second form of instability, as defined by Roobeek (1987), links the economic interpretation of technical instability with the identity of technical saturation. This term is used to describe the position where technical changes produce either: (i) an over capacity or, (ii) introduce a scarcity of economic materials such that a technical stagnation results. For example, where there are insignificant changes to demand patterns created by a technical change, these new technical adaptations are shown to be insensitive to the economic values which describe the characteristics of the change. Hence, this produces conditions for technical stagnation.

Lundvall (1988) using an economic interpretation defines a third form of technical instability generated by technical inefficiencies. For example, Lundvall (1988) states that instability can emerge when investments in new technologies is not paralleled with the qualities and reliabilities found in other technical improvements. For Lundvall (1988), this identifies a problem between existing sets of user-producer relationships and creates a reduction in the possibility of new relationships offered by changing the values in technical activities. This instability occurs because the interaction which takes place between changes in technical investment and demand patterns can highlight a conflict between the two activities which tends to manifest in terms of an economic inertia. That is, the interaction causes one of the activities to delay the change, yet this is normally reflected through the indirect influence of other economic characteristics.

From the two criteria used in this particular formative evaluation, economic descriptions of technical change do include accounts of technical instability. The three particular types of this instability are: (i) non-productive technical changes, (ii) technical saturation and (iii) technical inefficiencies. Any reference to an economic explanation of why such instabilities emerge, tend to focus on the interactions of certain economic variables. The indications from this are: (i) that economic descriptions concerning technical instability do not currently present any structural mechanism which illustrates how this instability can be reduced within an economic explanation of technical change, and (ii) whether such instability is actually a necessary characteristic within the process of technical change. From the criteria used and the results obtained, the System Two in a viable system model of technical change offers a means for explaining the economics associated with how technical instability emerges, and the necessary structural requirements to reduce this instability.

6.323 System Three and the Economic Selection in Technical Change

A System Three in the viable system model of technical change indicates that dependent relations exist between itself and Systems One and Two, and these define the functional activities of System Three in terms of: (i) control, (ii) coordination and (iii) direction. In this formative evaluation, the function and dependent relations of System Three are assessed in terms of current economic examples of technical change. The criteria by which this assessment takes place is: (i) identifying economic examples which illustrate a parallel function with that of System Three, and (ii) illustrating the structural similarities between the examples and the System Three.

Arthur (1988) uses the term technical competition to refer to the economic characteristics associated with the selection of new technologies. This particular term being based on the assumption that selection principles operate in a process of technical change which control, coordinate and direct the nature of the process. Hence, when new technical activities emerge, it can be inferred that various economic possibilities which are offered by the competing technologies in terms of: (i) different market places, (ii) the size of the consumer demand and (iii) the degree of competitive advantage, require a selection process by which a technical 'winner' is obtained and the technical change initiated. The problems of deciding which new technical activity to select depends on the selection procedure involving certain selection activities. Depending on the selection criteria different technologies can be adopted. This is identified in the following extract, from Arthur (1988):

> " When a new ... economic possibility comes along, usually there are several ways to carry it through. In the 1890's the motor carriage could be powered by steam, or by gasoline, or by electric batteries. In more modern times nuclear power can be generated by light-water, or gas-cooled, or heavy water, or sodium-cooled reactors. Solar energy can be generated by crystalline silicon or amorphous-silicon technologies. An AIDS vaccine may eventually become possible by cell-type modification methods, or by chemical synthesis, or by anti-idiotype methods."
>
> (Arthur, 1988, p. 590)

The economics of technical competition are described through a selection process and based on a continued comparison between technical adaptations and the prospect of a new technical possibility. This competition gives rise to either: (i) an economic flexibility offer by a new technology, or (ii) the possible continuation of economic stability offered by existing technical activities. In these terms, the process of technical competition operates by providing a means to maximise exploitable economic opportunities, that is, to utilise an economic rationality in order to identify and select any synergistic form of technical change. The analytical concentration on selection and competitive theories in terms of technical change is made with particular reference to Metcalfe's (1988, pp. 572-579) account of the principles of economic selection. As stated by Yates (1987), the most typical selection principle is based on the concept of an 'on-off' mechanism, whereby technical solutions can be divided into: (i) acceptable and (ii) non-acceptable states. However, if the category of acceptable states contains more than one technical activity, Metcalfe (1988) states that comparisons between the acceptable current technical practices should be defined by a selection criteria which includes a number of factors such as: (i) capital rate of return, (ii) capital/output ratios, (iii) unit costs of each technology and (iv) differential profitabilities.

From the theoretical analysis undertaken, the structure associated with economic descriptions of technical competition was taken from the work of Metcalfe (1988) and Robinson (1979 and 1980). In their accounts, which concern the economic principles of technical selection and competition, a structure was defined which incorporated four main functions used in a selection process. These were associated with: (i) demand selection, (ii) customer selection, (iii) payoff selection, and (iv) selection in terms of market share. Gold (1983) for example, states that the pay off selection is based on a wide array of very simple criteria. This includes the selection of a new technical activity based on analysing the ratios between expected reductions in man hours per unit of output and reductions in unit wage costs. A further selection criteria links the expected reductions in material requirements per unit of output with the changes in unit costs. Additionally a technical selection is made between the resulting cost savings which can be carried over into increased profits. In these cases, it appears that the actual process of economic selection is expressed by transferring the means of selection into a Boolean expression, in order to introduce a form of economic rationality into the process of selection. This can be observed in the works of Pope and Hauptman (1988), Reiganum (1981 and 1983) and Yates (1987). The output from this would present a particular 'direction' change in the values of certain economic variables used to express technical change. As Gold (1983) suggests, selection factors would subsequently 'control' aspects such as: (i) the cost of interruptions to production, (ii) the cost and outlays in readjusting preceding and subsequent technical operations, (iii) the cost of modifications, and (iv) the cost of new facility functions. Other aspects can also be assumed from this, for example by 'coordinating' changes to: (i) the cost of improvements to other operations, (ii) improvements in revenue and (iii) product quality. This provides the first definite formative link between the economic examples of technical change and the function of a System Three.

The interpretation of the function of a System Three parallels the economic activities associated with technical competition, and provides the basis with which an assessment of whether current economic thought links these activities to a particular structure. However, the majority of approaches which describe technical competition depend on the assumption of economic rationality (Metcalfe, 1988). This implies that whilst all information is known, it may be uncertain. The consequence of this is that any dependent relation between the activities of economic selection and the additional functions of technical change are not identified.

This occurs as a result of two factors which are derived from the approaches adopted by Robinson (1979 and 1980) and McCardle (1985) which: (i) use existing approaches to avoid the use of factors associated with the identification of the economic variables and their somewhat erroneous nature, and (ii) the tendency to base technical selections on current economic values rather than taking account of recent trends in such values. The uncertainty concerning the nature of economic values is reflected in the reliance on Boolean expressions, and is linked with the general assumptions that the accuracy of an information source is distributed normally, as illustrated by Pope and Hauptman (1988). Hence, the problems of deriving accurate economic values in order to generate a valid account of technical competitiveness is derived from assumptions concerning the uncertainties of information collection, rather than on the uncertainty with the information itself.

The System Three in a viable system of technical change offers a structural interpretation which removes the reliance on assumptions of economic rationality, as the dependent relations between the function of System Three and other functions of technical change provide the necessary information sources for a selection process. From this structure three sources of information can be identified which provide the basis by which technical selection can coordinate, control and direct the other functions of technical change. These are: (i) the internal economic state of the technical modes, (ii) information regarding the existing economic instabilities derived from technical changes and (iii) information regarding the nature of technical activities within the viable system environment.

It is from these considerations that the findings of the formative evaluation of the System Three and economic examples are deduced and are based on the criteria adopted. These are: (i) the actual function of a System Three is described within the economic characteristics as a means of technical selection which illustrates similarities with the economic description of technical competition. (ii) The structural basis identified in System Three and linked to other functions is not found in current economic descriptions. The explanation for this is found in the general assumption of economic rationality to describe technical competition. (iii) System Three offers a structural framework which removes the necessity to rely on the assumption that all necessary information is known, yet uncertain. This is achieved by identifying the dependent relations between other functions and the function of System Three. The effect of System Three is to provide a new economic framework with which to describe the interdependence between the functions identified in the viable system of technical change and technical competition. In particular, the structure provides an indication as to how technical competition is based on selection criteria which is generally concerned with economic payoff, defined through the activities of System One, and market conditions. This link between the competitive aspect of a System Three model and the 'economic markets' is clearly defined by Metcalfe (1988):

> "At the root of our review is the notion that competition is driven by technical variety, variety which is evaluated in economic terms by the prevailing market environment."
>
> (Metcalfe, 1988, p. 586)

It is this economic relationship between technical competition and prevailing market conditions which defines the nature of the formative evaluation on a System Four in the viable system model of technical change.

6.324 Economic Anticipation of New Technology

A System Four in the viable system model of technical change, provides a linkage of the anticipation function to the viable system environment and System Three. In this formative evaluation, the structure and function of System Four is assessed in relation to economic examples of technical change by using two criteria. These are: (i) identifying the function of System Four within the economic examples, and (ii) assessing any structural characteristics within these examples, to that expressed in a System Four.

The primary function of System Four is defined by the activities involved in technical anticipation and identified by the relationship held between the activities of: (i) identification, (ii) measurement, (iii) modelling and (iv) interpretation. In a number of economic examples of technical change this anticipatory function is reflected in economic forecasts of new technical developments. These economic forecasts provide a link between economic descriptions of technologies, and the forecast interpretation of future improvements. This particular aspect of technical change is identified in the following extract taken from Rosenberg (1982):

> "As soon as we accept the perspective of on going nature of much technical change, the optimal timing of an innovation becomes heavily influenced by expectations concerning the timing and significance of *future* improvements."
>
> (Rosenberg, 1982, p. 107)

An indication of how economic descriptions for the anticipation of new technical developments are identified, is provided by Gold's (1983) account of environmental scanning. The problem is that, according Gold's (1983) analysis, the ceaseless scanning of economic possibilities rarely, if ever occurs. What normally is found to be the case is that a casual eye is placed on a purported new prospect, but even then serious economic efforts to identify and monitor developments are often too costly to apply. In effect, Gold (1983) argues that environmental scanning is very often triggered by certain circumstances such as: (i) a threat to market share from a new technology or, (ii) a progressively weakening market position. These economic aspects provide the link between particular styles of technologies and standardised measures such as: (i) productivity or (ii) energy consumption improvements. Sahal (1979b) illustrates a number of these standardised measures which reflect improvements in particular technologies, and cites, as an example, the increases in average fuel consumption efficiency costings for farming technology.

In effect, identification of economic characteristics appears to be primarily determined by the type of measurement function used to obtain the appropriate technical forecast. This in turn, is reflected in the type of model used to forecast new technical improvements. Evidence presented from the majority of forecasting models, as described in Chapters Two and Three illustrate that many of these models are heavily based on the biological analogy and use the characteristic sigmoid curve, developed by Pearl (1925), together with other variations such as the Cobb-Douglas equation. This corresponds closely to the activities defined in the System Four which functions so as to anticipate new technical developments. That is, the structure of any System Four which is used to describe the activities of an anticipation system requires a model of itself in order to function. The most appropriate means to introduce such a characteristic, is to use an analogically related model. For example, in the viable systems model of technical change, it is assumed that the process of technical change is reflected by the characteristics held within the viable system. Hence, to model the anticipatory aspects of new technical developments, it is essential to utilise a viable system model and to link the model with the measurements undertaken. In the economic interpretation, such characteristics are assumed to function in a sigmoid fashion, and therefore measures are based on an analogical model using the sigmoid curve. In Chapter Three such a logical connection between the analogy adopted, and the form of measurement required was identified. For example, the biological analogy requires only a single unit measurement, simply because the basis of the model is an assessment of the time dependency of a particular variable.

However, this description of the economic anticipation of new technology is also associated with a high degree of a margin of error in its interpretation. This is principally derived from: (i) an inaccurate measurement and, (ii) a reliance on an analysis of factors linked by direct causal relations, rather than including indirect influences. These include factors such as: (i) increasing returns, (ii) economic externalities and (ii) the degree of interrelatedness. It occurs as a direct result of the type of model used for forecasting. The consequence is to be found in the interpretation of technical developments and the implication that this may have on the process of technical change. For example, the impact of such measures directly relate to the necessary triggers for assessing technical changes in terms of: (i) future payoffs, (ii) profitabilities and (iii) resource costs.

In principle, descriptions of economic anticipation for new technical developments is based on four areas. These consist of: (i) an analogical assumption, (ii) information acquisition, (iii) measurement and (iv) technical forecasting. The criteria used to assess the System Four of technical change illustrates that there is both a functional and structural correspondence to economic examples. The implications of this similarity offer two additional aspects which are derived from this evaluation: (i) although the function and structure between economic examples and System Four may be similar, the latter provides a new set of modelling and measurement characteristics which can be used to anticipate technical developments, and (ii) that System Four is related to other functions within the viable system model of technical change, whilst economic examples tend to illustrate a forecast of technical development in isolation to other aspects of technical change. As a consequence, an economic forecast tends to remain a theoretical forecast, until reasons for a fall in market share or changes in consumer demand are looked for.

Whilst no evidence could be obtained which illustrated a structural relation between the economic forecast of technical change and other functions in the process, the final formative evaluation considers structural and functional aspects associated with a System Five in the viable system model of technical change.

6.325 System Five and the Economic Identity of Technical Change

System Five in the viable system model of technical change represented the identity of a particular technical style (Perez, 1987) with which the process of technical change could take place. In this final formative evaluation, System Five is assessed in terms of economic examples of technical change using two criteria: (i) identifying the functional aspects of System Five in economic examples and (ii) an assessment of the structural relations.

The concept of an economic identity of technical change is recognisable through Schumpeter's (1939) concept of the production function. In this sense, each new technical development could be classified and assessed in terms of some form of universal economic criteria, usually based on the changes incurred in wages and prices as derived from the introduction of new technology. Although Schumpeter's concept of the production function has remained as a dominant aspect in explanations of technical change, its use has been reflected by analysis of prices and wages, rather than on the style of technology. Whilst the early theories developed by Schumpeter (1939) and Solow (1952) do indicate a technical style relevant to the modelling of technical change, the later theories, addressed by Dosi et al. (1988), focus far less on the economic characteristics of technologies, and draws more attention to the economic implications of technical change in their theories.

In the case of Schumpeter's work, as technical changes accelerated, more and more novel first time problems in terms of price and wage rate changes illustrated the changing conditions of technical development. Although a direct relation between new developments and internal actions of technical change is not illustrated by Schumpeter (1939), the changing parameter values of the economic structure reflects a need to create differential technical modes to deal with the different aspects of technical developments.

Perez (1987) does introduce the concept of a technical style for Fordist and post-Fordist technical products, wherein the economic characteristics of the styles are not specifically linked to technical change directly.

From the evaluation of System Five, it is considered that the current economic examples do not present a strong degree of similarity with both its structure and function. The implications for System Five are: (i) it can offer a stronger relationship between the economic effects of technical anticipation and the internal economic characteristics which describe technical change, and (ii) its function can provide a controlling mechanism which may explain the success of particular types of technical change and the failure of others.

This concludes the formative evaluation stage which has used particular criteria to assess the applicability of the structure and functions within the viable system model of technical change. The next stage uses a summative evaluation to compare the overall viable system model with some particular types of technical change as defined through economic descriptions.

6.33 A Summative Evaluation

A viable economic system of technical change consists of five integrated systems which constitute its viability. The formative evaluation of each of these five systems in relation to economic descriptions of technical change has highlighted that the economic evidence relating to each system currently varies between strong associations, as with System Four, to weak associations, as in System Five. As a consequence of this, the third stage in the evaluation process attempts to derive a comparative assessment between known economic descriptions of technical change and the description of the same type offered by the viable system model of technical change.

The summative evaluation of the viable system of technical change is based on a comparison between the viable system model and the four most common economic classifications of technical change. These are: (i) embodied technical change, (ii) endogenous technical change, (iii) neutral technical change and (iv) non-neutral technical change.

6.331 Embodied Technical Change

Heertje (1977) discusses the characteristics of technical change as embodied in labour and capital goods, in terms of the production function. The term 'embodied', is used to describe the process of technical change based on adjustments to levels of production being directly related to the installation of capital goods and the total amount of labour required in a given time period. New technical possibilities within this time period are no longer a choice concerning the nature of capital goods, but depend upon the degree to which labour and the remaining capital goods will be combined. The implication which concerns embodied technical change is that, labour and capital goods at the time of installation, may embody the state of the technology at that time, but that technical change becomes manifest through an adjustment to the productivity values of these factors, based on the year of installation. Thus, embodied technical change does not explain the expansion of technical possibilities, but simply the effect of the application of technology on the growth of production as observed by a shift in the production function.

Analysis of this account by a description presented by the viable system model of technical change, embodied technical change assumes a particular adaptation character, insofar as the process of adaptation can only occur through the changes in combination of capital goods and labour, and identified as a System One function. As a consequence, although the function appears part of System One, any local control of changes in labour or capital goods are not made explicit. In addition, the process of selection with respect to technical possibilities within the System Three, is based solely on the internal activities of System One over a specified time. That is, embodied technical change appears to be an exogenous characteristic, induced solely by the possible combinations of labour and capital goods with respect to time, and created by the interactive nature of the the two System One's describing the activities associated with labour and capital goods. Aspects of instability caused by this interaction are not considered as it is assumed that the process of selection, defined through the function of a System Three, removes all possible instabilities from the System One's. The anticipation function is unnecessary, as the derivation of new and emerging technical possibilities is not a function of embodied technical change. This result indicates that the interaction between new technical possibilities and the application of internal changes to existing technologies is removed, and therefore, questions concerning technical identity are redundant.

Hence, embodied technical change does not reflect the ideal form of a viable system of technical change. It does, however. represent a particular form of economic description which can utilise the structures and functions present in the viable system model to represent embodied technical change is a new way, and offer an alternative description and explanation of this type of technical change.

6.332 Endogenous Technical Change

Heertje's (1977) description of endogenous technical change makes the assumption that the passage of time ensures that various combinations of factors of production give a higher technical output without the need for new capital goods. To understand endogenous technical change, Heertje (1977) maintains that it is necessary to explain the expansion of technical possibilities by considering the choice made for a particular type of technical development. Technical changes do not always derive from changes in factors of production, but, takes into consideration that the distinction between different types of technical possibilities is, in general, made between a certain type of capital-saving or labour-saving technology. This leads not only to the savings in factors of production but also the identification of new technical products. Selection is then based on current wage bills or technical investments to determine which technical possibility is to be selected.

A comparison between endogenous technical change and embodied technical change indicates that a much closer parallel with the viable system model exists. Comparing endogenous technical change with the viable system model, a System One can be described as if it consisted of the production modes of capital and labour, and changes in these factors are also determined through the anticipated effects of new capital or labour-saving technologies, as defined in a System Four. The comparison leads to a process of selection, identified in a System Three through the criteria of investment or wage bills. A System Five introduces the need to compare new technical products with the existing technical identity, and hence, identifying the appropriate changes in technical characteristics through various combinations of capital, labour-saving technology or factors of production. A System Two is a redundant aspect of this interpretation and is a consequence of the nature of the assumptions used in the economic description. Endogenous technical change assumes that selection uses a rationality which optimises the prospect of technical change, and therefore instabilities which may occur are simply a consequence of an optimal technical change.

The characteristics of endogenous technical change are partially presented through the functional and structural descriptions offered by the viable system model of technical change. This summative evaluation indicates that economic descriptions can be expressed in a more detailed manner if the viable system model is used alongside the economic characteristics expressing exogenous technical change.

6.333 Neutral and Non-neutral Technical Change

The most common classification of economic descriptions of technical change are those of neutral and non-neutral technical changes. These particular technical changes, as described by Heertje (1977) develop from the influence of mechanisation on capital and labour ratios in the production process. Neutral technical change infers that marginal productivities of labour and capital increase to the same extent, whereas non-neutral technical change illustrates a difference in the rate of marginal productivities. It is these marginal productivities which describe the influence of new methods of production, such as capital or labour-saving technology or through factors of production, which produce a level of output which is qualitatively less dependent on capital or labour in the case of non-neutrality, or equally dependent in the case of neutral technical change.

Additionally, in non-neutral technical change, the concept of instability can occur because the change in capital proportions can sometimes be offset by changes to interest rate values. This instability is absent in neutral technical changes because: (i) the rate of increase in capital or labour productivities is equalled by the rate of increase in income derived from changes to output, or (ii) it is often assumed that the interest rate is given at a constant value.

Equating neutral and non-neutral technical change to the viable system model does indicate that a System One is in operation with regard to the factors of production defined as: (i) capital and (ii) labour. There is also a common link with a System Four in order to determine new technical possibilities. The selection process operating in a System Three for neutral technical change does rely on an association with stability criteria, that is, by assuming a given rate of interest or allowing technical changes to occur if income is parallel with equal changes in capital or labour productivities. For non-neutral technical change the stability criteria for selection is removed, and the instability which results is observed as an endemic feature of non-neutral technical change. In these two classifications it is not apparent that a System Five is explicit in these technical changes, although there certainly may be a case for such a system. In non-neutral technical change the operation of a System Five would be useful to reduce the instability between existing factors of production and new technical possibilities. This is less so in neutral technical change, as the instability is removed in the selection process.

From the evidence presented by the descriptions of neutral and non-neutral technical changes, the viable system model presents an additional functional and structural representation of these two types of technical change.

The implication of this summative evaluation reveals that the viable system model is an appropriate mechanism which can express existing descriptions of different types of technical change in an alternative and more informative manner. The conclusions to be drawn from this analysis illustrate that: (i) types of technical change currently described through economic examples do not all possess the characteristic of viability. (ii) The viable system model does illustrate how the types of technical change have different structures, yet all contain some of the essential functions assumed in the viable system model of technical change. (iii) The viable system model provides a new structural mechanism by which the different types of technical change can be closely examined.

This concludes the evaluation process using economic examples to assess the significance of the viable system model on current theoretical evidence. The following section is used to briefly summarise the key findings.

6.34 A Summary of the Findings from the Economic Evaluation Process

The objective for this particular evaluation process using economic examples, has been to establish the relevance of a viable system model of technical change to current economic evidence. The findings derived from the three stages used in the evaluation process provide some indication as to the applicability of the viable system model to the economic descriptions of technical change. These are:

(i) The viable system model of technical change provides a means by which the process of technical change can be represented in both a structured and functional framework in which economic considerations can be examined and utilised in a coherent manner.

(ii) There is positive indication that the economic descriptions of technical change can be reinterpreted within the functional and structural framework of the viable system model of technical change. The particular areas of similarity concern the functions of: (a) technical adaptation, (b) selection and (c) anticipation, whilst the formative evaluation also described how the structural aspects within each system might provide a more useful framework by which existing economic examples of technical change might be characterised.

(iii) The summative evaluation presented an assessment of the comparison between different types of technical change as described through economic interpretations and the ability of the viable system model of technical change to explain the structural and functional significance of each type. The findings have demonstrated that the viable system model of technical change offers a powerful structural and functional framework for reinterpreting the economic types of technical change. This novel and alternative analysis provides: (i) an extension to existing economic descriptions and (ii) a means by which explanations and understanding of how particular types of technical change can emerge within a general process of technical change.

The question concerning the applicability of the viable system model to human activity description of technical change is to be considered in the next section. This evaluation covers the same three stages which were conducted on the economic descriptions. The implication is that: (i) this further evaluation will help to establish whether the viable system of technical change is a comprehensive system scientific model and (ii) provide the necessary evaluation of an alternative example of technical change which may then be used in a further comparative evaluation of the viable system model between the two examples in a meta-evaluation (Summers, 1990).

6.4 Human Activity Descriptions of Technical Change

Early investigations into the human aspects of technical change were carried out by the 'Liverpool Group' (Mumford, 1986). Their particular interest lay in the relationship between technical change and industrial relations, with the primary concern being with the behaviour of shop floor personnel resulting from changes in technology. The views expressed by the Liverpool Group advocated that technical changes would inevitably produce human resource displacement within firms. In addition to this, the general conclusion considered that particular behaviours could themselves be derived as dependent characteristics of these changes. These sociologists relied upon, as the basis of their analysis, the concept of the socio-technical system to describe the human activity problems associated with optimal technical changes in terms of the general characteristics of de-skilling, unemployment and individual alienation. Mumford (1986) indicates the following problems which these investigations have produced:

> " Until recently behavioural scientists have been reluctant to question the values of technical specialists: they have also not seen the necessity for relating outputs to inputs. They have been prepared to study the consequences of the technology without attempting to identify the technical, economic and social factors present at the design stage which led to the choice of a particular technical solution, and therefore to a set of specific consequences."
>
> (Mumford, 1986, p. 14)

In this context, examples of technical change have been described by: (i) sociologists, (ii) anthropologists and (iii) behavioural scientists. These particular descriptions of technical change relate to various associations with human activities. In particular the variety of these descriptions of technical change provides a diversity which includes aspects of culture, psychology (in particular Gagne's (1962) description of psycho-technology), ergonomics and behavioural aspects (Dimond and Ellis, 1988). These human activity descriptions of technical change are becoming more integral with the effects of technical changes, particularly with post-Fordist technical changes.

The evaluation proceeds using: (i) needs evaluation, (ii) formative evaluation and (iii) summative evaluation, is to be carried out on the viable system model of technical change.The evaluation will be conducted through assessments which concern current examples of human activity descriptions of technical change.

6.41 A Needs Evaluation

The needs evaluation considers the question, is there a particular need with which the viable system model of technical change can provide to current human activity descriptions of technical change? In many respects the quotation of Mumford (1986, p. 14), presented earlier, indicates that the viable system model of technical change could provide a certain need. That is, to provide a function and structure by which human activities can be used to provide a viable process of technical change without a strong reliance on economic or engineering considerations. The viable system model provides a design structure within which the human activity can provide the necessary functions in an appropriate structural framework.

Kennedy (1962) argues that the most important psychological problem in relation to technical change is the necessity to organise people, Johnston, Kast and Rosenzweig (1984) extend such a recognition to the ability to manage the activities of people in relation to technical change. The viable system model provides the minimum functional and structural requirements by which the design, organisation and management of human activities in relation to technical change can be accomplished.

To assess the implications of this need, the next stage of formative evaluation will assess the applicability of the viable system model of technical change to current human activity descriptions of technical change. By using criteria based on the structure and functions of the viable system model, the evaluation considers how effective the need identified for the viable system model to human activity descriptions may actually be.

6.42 A Formative Evaluation

The formative evaluation to be carried out between the viable system model of technical change and human activity interpretations uses the same criteria as expressed in Section 6.32. The criteria is based on the structural and functional aspects of the five system descriptions presented in the viable system model, and used to evaluate whether such structures and functions are applicable within the particular examples of human activity used.

6.421 System One and the Human Aspects of Technical Adaptation

At the centre of System One activities associated with technical adaptation, is the presence of those activities which describe the changing characteristics in technical developments as they occur. The criteria used to assess whether this adaptation function and structure of a System One are present within current human activity descriptions are: (i) the identity of the technical modes and their local regulators of adaptation and (ii) any structural similarity between the System One and human activity examples of technical change.

Elizur and Guttman (1976) define the particular behavioural characteristics associated with technical changes, and in particular to changes in computer technology, as behavioural modalities. These modalities are concerned with: (i) instrumental, (ii) cognitive and (iii) affective activities of the individual.

Instrumental modality is defined as those human actions which are reflected by the implementation of new technology. It emphasises those occupational aspects which are concerned with the implementation of a new technology or, the actions associated with the use of such a technology. The second behaviour modality of cognition, is defined by the actions directly related to the necessity to introduce new technologies. These consist of those skill requirements which are necessary to perform technical operations. The affective behavioural modality is primarily associated with human attitudes feelings towards new technology. In this respect, the affective activity describes those aspects of human action which are identified as necessary to generate the appropriate form of the technical change.

Elizur and Guttman (1976) empirically tested these behaviour modalities with regard to the relationship between employees and new computer technology. However, the actual characteristics of these modalities were hidden from their results. These three activities provide a particular classification and parallel the three technical modes as expressed in each System One. The implication drawn from this is, that the instrumental, cognitive and affective modalities can be classified as human activity descriptions of technical characteristics. To evaluate this correspondence between System One and the conclusions from Elizur and Guttman (1976), these three modes were analysed by using the work of Clark, McLoughlin, Rose and King (1988) in order to provide a more comprehensive assessment, in defining the presence of local regulation and any applicable structure.

By using the Clark et al. (1988) account of the process of technical changes in telephone exchanges a more detailed assessment of the three technical modes can be made. Technical changes in telephone exchanges took place over the period 1970 to 1986. It introduced new human activities associated with the technical 'switch' from Strowger to the new TXE4 technology. These activity changes were principally classified in terms of: (i) work tasks, (ii) skills and (iii) role behaviour. The activities within these categories reflected a particular type of technical change which was taking place.

The data, collected by Clark et al. (1988), does illustrate how the characteristics of instrumental, cognitive and affective activities are altered by the transition from Strowger equipment to the new TXE4 technology. In the three examples below, it will be shown that the adaptation to new technology does not introduce new activities, but reflects certain changes in their characteristics. This also identifies a particular example of the human activity characteristics which describe a process of technical adaptation.

(i) The analysis of the changes in work tasks resulting from the introduction of new TXE4 technology provides a similarity with aspects of instrumental activities. The principal work task for all telephone exchange technology is defined in terms of maintenance criteria. Therefore, the changes to instrumental activities were considered by representative changes in the type of maintenance tasks undertaken as a result of the new technical introduction. Such activities for the Strowger equipment consisted of:

(i) mechanical adjustments, (ii) cleaning, (iii) soldering, (iv) wiring and (v) faulting. With the new technology, a number of these activities were made redundant, as the new electronic applications had reduced the number of moving parts in the technology. As a result, the instrumental activities were reduced to the tasks of: (i) mechanical adjustments, (ii) soldering and (iii) faulting. The consequence of this new technical change, as defined by instrumental activity changes, and reflected by the maintenance requirements, illustrated that there was a decrease in the skill value which could be judged by changes to the amount of work undertaken. However, there was no indication as to how this human activity change had been regulated, only that those employees which moved to the new technical activities had been assessed on their experience using existing telephone exchange technology. The overall indication was that the change had been determined by the new technical requirements.

(ii) The cognitive aspects associated with telephone exchange technology provided a link with those activities which could be identified in terms of new technical training. Clark et al. (1988) categorised this activity in terms of: (i) manual and (ii) mental skills. The change in the technology required a higher level of training and expertise as Strowger technology only required an understanding of electrical, engineering and faulting knowledge. The new TXE4 technology required new skills. Clark et al. (1988) defines these as: (i) system and faulting knowledge, (ii) paperwork, (iii) diagramming, (iv) the use of maintenance aids and (v) the implications associated with maintenance. The introduction of this new technology, required that the training needed a more cognitive approach to the maintenance of the new TXE4 equipment. The effect was that the technical change replaced the repetitive and routinised work, with more 'dive in' techniques which had to be used on an irregular basis and concerning different problems. Thus, whilst instrumental changes reflected a de-skilling in the number of jobs undertaken, the technical changes identified in the cognitive activities required a higher level of training. The following extract from Clark et al. (1988) illustrates this difference in the different human activities associated with the same technical change.

> " [TXE4 work] is very much de-skilled... so far as Strowger is concerned, you've got to be good at two things. You've got to be able to make mechanical adjustments and you've got to know how the thing works. TXE4, you've only got to be able to know how the thing works because there is no mechanical adjustments..."
>
> (Clark et al., 1988, p. 118)

Those employees wishing to transfer to the new technical activities were controlled by an assessment of their prior training and education. From this indication it appeared that the cognitive activities were controlled through a level of educational development.

(ii) The most significant form of observed change between the Strowger and TXE4 technologies were that the skills in Strowger technology could be learned incrementally and by trial and error, whereas in the TXE4 exchanges, trial and error could seriously affect customer service. The consequences of this conclusion made by Clark et al. (1988) could be seen in the changes to affective behaviour as a result of the new technology. For Strowger technology, the employees required the characteristics of: (i) patience, (ii) logic, (iii) deductive ability, (iv) interpretation, (v) visual and oral abilities and (vi) even a knack or 'feeling' for the technology. For the TXE4 technology such affective activities were reduced to include: (i) a deductive ability, (ii) interpretation, (iii) intuition and (iv) an ability to think before acting. These changes generally resulted in a problem of employee confidence in the operation of new technology.

To control the changes in affective activity, the criteria which was adopted by the managers of the telephone exchanges was determined by the enthusiasm for the change exhibited by the employees and the general acceptance of a need for the technical change.

Whilst the process of technical adaptation from Strowger to TXE4 equipment is technically associated with improved performance and reliability, it is also reflected in terms of human activity, through a reduction in: (i) works tasks, (ii) an increase in technical skills of employees and (ii) a decrease in their affective behaviour. For Clark et al. (1988), the control factors identified provided an ability to: (i) retrain, (ii) alter work content and (iii) motivate employees within the telephone exchanges, in accordance with a successful technical change.

Three particular findings emerge from this formative evaluation. These are: (i) that the human activity descriptions of technical change do provide certain modalities which add insight into the examples of technical adaptation. These modalities present a similarity to those anatomical modes discussed in the viable system model of technical change. (ii) There is evidence to support the structural relationship between the activities and their local regulators in the example used, however, the System One provides a coherent framework by which such analytical approaches can provide a more informed description of the human aspects of technical adaptation. (iii) The examples used in this formative evaluation suggest that certain human actions are determined by technical attributes. Whilst this may be applicable, the viable system model of technical change implies that there is a particular structured framework by which this association can be made which is not identified at present.

To present a more detailed structural account between the viable system model of technical change and the human activity descriptions, an assessment of the function and structure in a System Two will be conducted.

6.422 The Instability of Human Action in Technical Change

The criteria used to evaluate a System Two of the viable system of technical change with human activity examples, is based on three considerations, (i) an ability to identify the characteristics of instability found in the human activities associated with technical change, (ii) to assess whether current theories exist which provide a structure which helps to explain why such instabilities occur and (ii) how those instabilities are reduced.

The assessment relies on the work of Keen (1981) and his description of the possible compatible relationship between human activity and the introduction of a new technology. In Keen's (1981) account of the relationship between human activity and its compatibility with new technical introduction, three key areas of instability are discussed. These instabilities are the result of a combination of human actions which are used to emphasise an incompatibility between changes in human activity and corresponding technical changes. These are defined by Keen (1981) as: (i) social inertia, which describes a set of socially related events which unknowingly deny the process of technical change, that is, "... no matter how hard you try nothing seems to happen..." (Keen, 1981, p. 24). (ii) Pluralism, which produces a conflicting set of priorities, objectives and values which can be held by different individuals or groups which hamper the process of technical change, and (iii), counter-implementation, describing a practical approach which introduces human resistance to the technical change, usually by those who feel the human price of the change far outweigh the benefits.

Keen (1981) argues that social inertia is principally caused by perceptions which are: (i) inevitably selective, (ii) contain biases and (iii) illustrate personality differences with an inaccuracy over the functions of new work tasks. The implication is that this instability emerges at the interface between the modalities expressed by Elizur and Guttman (1976) as: (i) affective behaviour, seen in terms of perceptions and (ii) instrumental activity identified by the changes to work tasks.

Pluralism is viewed by Keen (1981) as a consequence of different perceptions towards new skill requirements identified by the technical changes. It suggests that the technical instability can defined by human action which emerges from: (i) uncoordinated cognitive activity, in terms of training techniques and (ii) instrumental activity, seen in the individual differences in the type of work tasks.

Finally, the characteristic of counter-implementation, as discussed by Keen (1981) is described in terms of the human ability to disrupt the technical change through the diversion of work tasks, such as in the work tasks of a project, and the 'political' biases of individuals. This type of instability would correspond to the uncoordinated interaction between: (i) instrumental and (ii) affective modalities.

Although these three characteristics define the nature of the instabilities in human activity descriptions of technical change, their identity does not illustrate whether the instability can be removed or indeed should be. As Keen (1981) points out, there is a necessary need to identify instability which leads to unsuccessful technical changes and also, to identify the instability which highlights genuine human activity problems within the process of change.

> " Obviously, there is a fine line between honest resistance to a project one feels is misguided and selfish sabotage of a necessary innovation."
>
> (Keen, 1981, p. 28)

Although certain controls concerning the changing human activities associated with technical change have been identified, a structural framework between Systems One and Two in the viable system model of technical change is not illustrated in any current example using human activity descriptions of technical change. What is accepted, by Clark et al. (1988), is that these local controls do have some basis for controlling these technical modes. For example, to reduce instability found in instrumental activity McLoughlin and Clark (1988) suggest the use of damping mechanisms would likely be defined as: (i) recruitment, (ii) displacement of personnel, (iii) appraisal and (iv) selection. In Salt 's (1990) discussion on the new skill requirements for information technology in Papua New Guinea, an interpretation of his analysis identifies that certain local controls could be defined by changes to skills training either at: (i) the work place or, (ii) on courses in order to damp instability found in cognitive activity. To counter the instability derived from affective behaviour, which can be identified from the form employee involvement, Blackler and Brown (1986) suggest the targeting of particular personnel problem areas involved through changes to reward systems, or through personnel involvement issues. However, there does not appear to be any means of coordinating these local controls from the theoretical evidence, and as a result these independent actions do not imply that an overall ability to dampen instabilities in the human activity process of technical change is currently available.

The findings from this assessment are: (i) the identity of the characteristics associated with human instability in a process of technical change are: (a) pluralism, (b) social inertia and (c) counter-implementation. (ii) There does seem to be some evidence to support the concept that local controls do have the appropriate mechanisms to damp out such instability but that they do lack any form of coordination. (iii) As there is no current theoretical evidence for a coordinating mechanism, the System Two structure and its particular function of coordination provides an appropriate framework by which an explanation of instability and the ability to reduce its effects may operate. (iv) This framework may offer some guidelines by which the coordination of these local controls may be able to distinguish between the 'honest' instability derived from problems with technical change and the consequences of sabotage from such human action.

6.423 System Three and Technical Selection through Human Activities

The criteria used in this evaluation of System Three, assist in the analysis of the application of human activities to the selection criteria for the adoption of new technical developments in terms of: (i) the function and (ii) the structure proposed by a System Three. The theoretical evidence used to assess the applicability of a System Three to explain human activity in technical change is based on information derived from the works of Porter (1987), Blackler and Brown (1986), Clark et al. (1988), Elizur and Guttman (1976) and Sparrow and Pettigrew (1988). These information sources are used specifically to evaluate a theoretical association between three aspects in System Three. These include: (i) to identify the essential human activity components assumed in System Three, (ii) to determine the type of information used in selection, by identifying the historical knowledge base on human activities associated with technical development, and (iii) to assess how a the function in a System Three may be linked to other activities associated with human activity examples of technical change.

According to the work of Sparrow and Pettigrew (1988), there is a fundamental need to define a human 'resource' selection model with regard to technical changes. In their conclusions, technical selection provides a basis for the improvement of: (i) employees roles, (ii) work tasks, (iii) skills, and (iv) in general, to illustrate selection by adjustments incurred through employment conditions as described by new technical developments. This evidence provides a direct link with the technical modes as evaluated through Elizur and Guttman's (1976) analysis of technical change.

Sparrow and Pettigrew's (1988) analysis, illustrates that a process of selection of new technology which is based on the implications derived from human activity, should be based on: (i) an ability to maintain a congruent set of goals, beliefs and attitudes, (ii) an ability to shift the human activities of roles , tasks and skills in relation to the possible technical adaptations and (iii) an assessment of the necessary changes to training programmes, such that a new technology would make the most efficient use of a firms repertoires of skills, tasks and roles, in terms of its technical operations. Such selections would lead to a higher degree of multi-skilling ability. By linking the selection process to new technical possibilities rather than just technical adaptation, the new information would illustrate potential development in employee abilities, which in turn, would add value to the firm and broaden the individuals worth.

Whilst Sparrow and Pettigrew (1988) offer these activities as a potential means of selection for new technology, they state that such a selection process in the computer supplier industry can only be successfully implemented under a consistent mechanism. System Three provides both the functional and structural framework which can be adopted for these characteristics such as: (i) skill and training requirements, (ii) volume of personnel, (iii) type of personnel and (iv) working conditions. In figure 6.3 the structural framework of System Three is illustrated in terms of the implications that can be inferred from the use of this human activity example from Sparrow and Pettigrew (1988).

The human activity example of technical change does indicate that there is a particular need for both the structural and functional framework of a System Three in the viable system model of technical change. The findings include: (i) that an appropriate selection process of new technology is applicable, using human activity factors, which can add value to the firm and broaden the individuals worth and (ii) System Three provides the structural requirements which link a selection process to other human activity function in technical change.

Structures Between Systems In The Viable System Model Of Technical Change	Definition Of The Dependent Relations	Structural Implications Of Technical Change Using Human Activity Characteristics In System Three
SYSTEM THREE ↔ SYSTEM ONE	1. A structured link to primary activities of SYSTEM ONE	To create and maintain a congruent set of goals, beliefs and attitudes to make the most effective use of new technology
	2. A structured link to local regulators of SYSTEM ONE	The development of people to both improve their value to the firm and broaden their individual worth in terms of technological developments
SYSTEM THREE ↔ SYSTEM TWO	3. A coordination link to SYSTEM TWO	Improvement in the quality of the managerial process through a formalisation of traning programmes and developing an employee complimentarity to new technology
SYSTEM THREE ↔ SYSTEM FOUR	4. Structured link to SYSTEM FOUR to identify the possibility of technical advance	Improvements through integration or differentiation of roles, tasks and skills and the adjustment of employment conditions for job incumbants in relation to technical advance

Figure 6.3 the structural framework of System Three through human activity descriptions of technical change

6.424 Anticipating Human Activity Changes in Technical Developments

The viable system model of technical change defines the function of a System Four as anticipatory. It is structurally related to the functions of Systems Three and Five and also used to monitor events in the viable system environment. The criteria used to evaluate the use of such a system in current human activity examples of technical change are: (i) to identify the components of technical forecasts which use human activity characteristics and (ii) to identify any structural relation with the particular functions in technical change.

The closest theoretical evidence which supports this particular aspect in a viable human activity system of technical change are found in the assumptions in the labour process theory developed by Braverman (1974). Braverman's (1974) account of the process of technical change links the consequence of managements' desire to change the level of skill and autonomy of the workforce with the introduction of new technology. He argues that the anticipation of management used in de-skilling the workforce, highlights the subsequent introduction of new automated technologies. However, whilst some similarity is evident to the anticipation function in technical change, Braverman's (1974) arguments have increasingly been under attack from a number of theorists including McLoughlin and Clark (1988, p. 37) who state that "...the argument does not present a complete or explanatory framework."

The labour process theory assumes that the economic imperative of capital accumulation is of less importance than aspects of the labour process and the workforce in general. In addition, Braverman (1974) assumes that the anticipation of technical change is conditioned solely by the de-skilling requirements of management. The effect of this is that whilst there is a limited amount of support for the existence of an anticipation system as defined through associations with human activity in general. The simple relationship as described by Braverman (1974) is in reality much more complex and ambiguous. Consequently, the theoretical evidence provides little support for the concept that changes in human activities can be used to illustrate the characteristics of an anticipation system.

There is evidence, particularly from the assumptions of technical determinism, and to a limited extent, from assumptions in the socio-technical system theory, which suggests that such aspects associated with technical anticipation are not currently derived from the human sphere of influence, but from the more technical or economic aspects of technical anticipation.

There is little evidence from the examples of technical change using human activity descriptions to suggest that both the structural and functional framework assumed in a System Four are currently applicable. The findings from this assessment are: (i) that the structural and functional aspects of the System Four are dominated from outside the human activity descriptions, that is, anticipation of technical change is derived from economic and technical changes rather than as a desire to alter: (i) working conditions, (ii) skills and (iii) tasks. This is a consequence of the assumptions of both technical determinism and to some extent socio-technical systems theory. Socio-technical system descriptions of technical change tends to link economic and human activity aspects at the same level of recursion, this is how the social structure and technology co-determine outcomes within the organisational context Thus, Collins (1986), argues that the technical system presents the social system with different opportunities as it evolves, and this affects the strength of the relationship between the social system and the process of technical change at the same level of recursion. (ii) As this occurs at a single level of recursion, according to the viable system model there can only be one anticipation function. This is currently determined by the technical characteristics and given through economic descriptions rather than through human activity descriptions. This provides one explanation of why there is little theoretical evidence to suggest that an anticipation system is defined in terms of human activities. (iii) Anticipation through potential changes in human action is currently considered too simplistic and ambiguous in relation to technical change. This assumes that this particular function operates without reference to other functions operating in technical change.

6.425 System Five and Technical Identity through Human Action

The final aspect in this formative evaluation considers the application of a System Five in human activity examples of technical change. The criteria used are: (i) to identify the function of a System Five in the examples of human activity descriptions of technical change and (ii) to define any structural framework used by such examples.

The findings from this assessment reveals that, at present, there is no theoretical evidence which supports and illustrates the function or structure assumed in a System Five. However two aspects have emerged: (i) that analogies reflected in cognitive as well as in cultural models may provide some insight on a possible technical identity as defined through human characteristics, and (ii) the examples from socio-technical system theory, and in particular the work of Collins (1986) generally point to technical identity being defined by engineering or economic criteria, although there is some indication that a particular style of de-skilling technology and multi-skilling technical change (Sparrow and Pettigrew, 1988) is accepted. The effect of this though, is to imply that current analysis of technical changes operate at a higher level of recursion, which absorb any direct reference to the identity of a technical style as defined through human characteristics.

This concludes the formative evaluation of the five systems in a viable system model of technical change. The final stage in the evaluation process considers a general comparison between particular types of technical change as described through human activity and the description which is offered viable system model.

6.43 A Summative Evaluation

This summative evaluation is used to assess the viable system model with known types of technical change as described within human activity examples. The assessment is aimed at analysing the the configuration in terms of its overall structure and function of viability. The comparison is used to extend the formative evaluation of the individual structures and functions in order to provide a more comprehensive assessment of the viable system model of technical change.

However, the definitions of technical change types as described in human activity examples are scarce. Indeed, the only available technical change type is referred to by Collins (1986) as de-skilling technical change. The implication of this is that such technical change does not involve the five system functions offered by the viable system model of technical change. Therefore, this summative evaluation focuses on two particular questions: (i) are there human activity types of technical change? and (ii) what are the implications for the viable system model of technical change?

6.431 Are there Human Activity Types of Technical Change?

Collins (1986) account of process technology change in terms of socio-technical theory, indicates that the human activities associated with technical change do rely on the effect of economic or technical characteristics to determine the changes to human activity in relation of technical change. Collins (1986) states that whilst the social system affects it own capacity for change in terms of the introduction of new technology, it is usually the technical system which provides the opportunities and constraints on the degree of change. From this interpretation and from comments by Clark et al. (1988), McLoughlin and Clark (1988) and Sparrow and Pettigrew (1988), there are only two specific types of technical change which is characterised entirely by the changes in human activity. These are: (i) de-skilling and (ii) multi-skilling technical changes.

Beer (1979) states that the main characteristic of viability is the ability to maintain a separate existence. In this context, viability is defined by the interaction of five systems associated with technical changes. The formative evaluation identifies that the possibility of five interactive systems in a viable system model of technical change can provide both a structural and functional framework which extends beyond current theoretical approaches. The implication is that the framework offered can introduce particular types of technical change which use human activity characteristics. The consequence of this is that a typology of technical change described by a viable system of human activity is potentially available. Whilst there exists certain types of technical change in relation to human activity, such as: (i) de-skilling and (ii) multi-tasking technical changes, these can be defined within the activities of a System One, rather than as a result of the interactive effects of the different types of human activity functions. The indication must be that the viable system model can present a particular human activity type of technical change.

This summative evaluation has been unable to compare particular human activity types of technical change with the viable system model. The implications from this are: (i) that the definition of the types of technical change, as if they could be reflected solely by the characteristics of a social structure denies the independent nature of technology and its association with other aspects (McLoughlin and Clark, 1988). (ii) That the types of technical change can only be reflected in certain theories such as (a) techno-economic or, (b) techno-sociological, which co-determine the nature of technical change. (iii) The viable system model of technical change offers both a new structural and functional framework by which a typology of technical change types may be defined. (iv) The co-determining link identified in techno-economic or techno-sociological theories can be restructured and presented through multi-level recursions, using the structure and functional framework of the viable system model.

This concludes the evaluation process of the viable system model with human activity descriptions of technical change. The following section briefly summarises the key findings.

6.44 Summarising the Findings of the Human Activity Evaluation Process

The three stages of needs, formative and summative evaluation of the viable system model of technical change in relation to human activity descriptions of technical change have been completed. The relevance of this viable system model to the human activity examples is summarised in the general findings of the evaluation process as:

(i) The viable system model of technical change provides a structural and functional framework within which human activities can be organised in such a way as to present a viable process of technical change. This creates a framework which produces a viable system design of the human activities associated with technical change which in turn helps to establish the successful organisation and management of technical changes.

(ii) The five system functions and their structural relations in the viable system, model provides a new means of explanation of the human activity descriptions of technical change. The formative evaluation, illustrated that certain aspects concerned with the behaviour modalities and instabilities involved in technical change could be reinterpreted within the viable system model. Yet, other functional aspects together with their structural relations provide a appropriate means by which an extension of current theoretical descriptions of human activities in technical change might be achieved.

(iii) This is made more apparent in the finding of the summative evaluation. Two types of technical change were identified from human activity examples: (a) de-skilling and (b) multi-skilling technical changes. The interpretation of these types of technical change were made in relation to changes in the System One activities. The implication of this is that the structure and functions associated with the viable system model of technical change could provide the necessary framework to provide a typology of technical changes defined in human activity characteristics and that current socio-technical systems theory concerning technical changes which illustrate the co-determining forces of technical change, might be extended by integrating the viable system model in the form of multi-level recursions.

From the summary presented in each of the two evaluations conducted on the viable system model of technical change, the next section presents the conclusions for Chapter Six. In addition, it provides an final assessment of a comparison between the findings in each of the two evaluation processes through a meta-evaluation stage (Summers, 1990).

6.5 Conclusions

Has the viable system model of technical change proved to be a comprehensive system scientific model? This question, posed in the conclusions of Chapter Five, has been considered through three particular stages of an evaluation process in: (i) economic and (ii) human activity examples of technical change. It is from the findings in these two evaluations of the viable system model of technical change which produce the following conclusions:

(i) The viable system satisfies the particular needs of both economic and human activity examples of technical change. This is defined in terms of its structural and functional framework in which a more coherent description and explanation of the particular activities of technical change can be defined. This presents a framework which can help in: (a) the organisation and management of people and (b) the design and management of the financial activities which operate in relation to technical changes.

(ii) The viable system model containing its five system functions and dependent relations provides for a significant reinterpretation of technical change. In particular these include; (a) the technical modes which provide the fundamental characteristics in the technical change can be used to define the particular changes in both economic and human activity examples. (b) The identification of instabilities in both examples is explained by the structural relations held between the anatomical modes and System Two, illustrates a structural mechanism which can be used to coordinate the damping of such instability. (c) System Three was found to present the selection function of new technology in both economic and human activity examples. The viable system structure indicates that the selection process should be integrated with other functions within the process of technical change. (d) Whilst the anticipation function could be identified with the economic forecasts made for new technical developments, the indication is that a general framework within a social forecast of the implications of technical change are not currently evident. The System Four provides a means by which such a forecast can be attempted, in relation to the necessary activities and dependent relations required. (e) The formative evaluation of System Five in both economic and human activity examples indicated that within the overall process of technical change there should be a balancing mechanism which supports a particular style of technology. Whilst this function was not evident in either example, the viable system model suggests that this function and structure is a necessary feature which helps to explain the success or failure of certain technical changes.

(iii) From the summative evaluations the following conclusions are drawn: (a) the viable system model provides a new framework through which a reinterpretation of types of technical change can be defined. (b) It offers a means by which the viability of technical change can be assessed. (c) It creates a structure by which a typology of technical changes can be created, and helps to provide an explanatory framework of the necessary functions of technical change.

From this evaluation process, which has considered current theoretical descriptions of technical change, there is clear evidence that the viable system does provide a comprehensive system scientific model for the understanding and management of technical change. This conclusion is based on two major considerations: (i) the viable system model provides an appropriate mechanism which helps to describe and explain some of the present theoretical examples of technical change and (ii) that the viable system model helps to create an extension to current theoretical descriptions of technical change by providing (a) an acceptable structure, (b) appropriate functions and (c) an interdisciplinary model for technical change.

This rigourous evaluation has considered theoretical examples of technical change. In order to fully evaluate the viable system model of technical change, the question concerning how comprehensive the system scientific model is, must be answered in relation to a practical evaluation process of technical change. How does the viable system model provide a comprehensive account, in relation to practical technical changes? Chapter Seven now considers this question in relation to the same three stage evaluation process, of a needs, formative and summative assessment.

CHAPTER SEVEN

A PRACTICAL EVALUATION OF A VIABLE SYSTEM OF TECHNICAL CHANGE

7.1 Introduction

The evaluation process of Chapter Six established that the viable system model of technical change is a comprehensive system scientific model based on the theoretical examples used. This was achieved through three particular aspects of the model: (i) its acceptable structure, (ii) the appropriate five system functions and (iii) as an interdisciplinary framework. Yet from these conclusions, a principal question emerged, does the viable system model provide a comprehensive account of technical change in practice?

Chapter Seven describes an evaluation process of the viable system model of technical change by providing a practical example within a U.K based microelectronics firm, International Computers Limited, (I.C.L.) at their Manufacturing and Logistics site, Kidsgrove, Staffordshire. A background to the general activities of I.C.L is presented in Appendix I.

This Chapter is presented in three main sections: the first section discusses the evaluation process carried out at I.C.L, to assess the viable system model of technical change within a technical business context. The second section presents the stages of the evaluation process and their findings. The final section details the conclusions obtained from this evaluation process.

7.2 The Evaluation Process

The evaluation process described in Chapter Six and containing the three stages of: (i) needs, (ii) formative and (iii) summative assessments, is also used in this Chapter to evaluate the viable system model of technical change in relation to a practical example.

To generate the information for these particular evaluations three activities preceded this evaluation process. There were: (i) data collection regarding the nature of technical change at I.C.L, (ii) classification of information obtained and (iii) feedback of the information to selected I.C.L personnel in order to determine whether the information derived had been accurately interpreted. The framework for this evaluation of the viable system model is illustrated in figure 7.1.

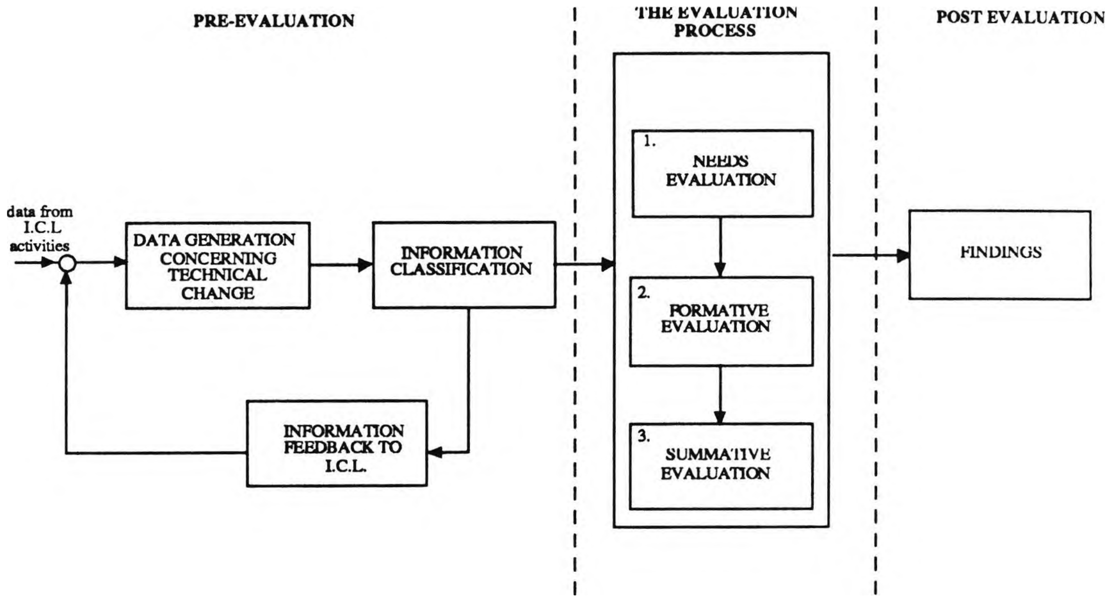


Figure 7.1 activities leading to information needed for a practical evaluation process of the viable system model of technical change

The data collection activity of technical changes at I.C.L, were obtained from material produced over four visits, each conducted over periods varying from 1 to 5 days covering the period March 1989 to January 1990. This activity was initiated during an invited participation I.C.L technical workshop. This workshop was used to discuss the application of new information technology in I.C.L, in order to reduce the time it took to place new products onto the market (Dimond and Ellis, 1989b). Additional data, was obtained during a series of interviews with I.C.L personnel at the Manufacturing and Logistics site, which included: (i) design engineers, (ii) system managers, (iii) production controllers, (iv) operations managers and (v) advanced systems managers.

The second activity generated certain classifications of the data with the resulting information being used to describe technical changes in terms of the following areas: (i) manufacturing, (ii) design, (iii) design-manufacture interface, (iv) finance and (v) future systems.

The final activity resulted in the feedback of these classifications to I.C.L's Business Liaison Manager, in order to establish whether the data obtained had been accurately interpreted such that the evaluation process could begin. Based upon results of this feedback, the basis of the evaluation of the viable system model of technical change was to be linked with the technical changes at I.C.L.

7.2 Identifying Technical Change at I.C.L

I.C.L in general, readily identify with the 'promise and the reality' of technical change (International Computers Limited, 1986). The 'promise' of new technologies is based on an assumption that they introduce such aspects as: (i) new unique characteristics, (ii) new opportunities, (iii) high profit potential, (iv) the destruction of competition, (v) added value and (vi) greater asset utilisation. But with such 'promises' the associated 'reality' of new technology is very often: (i) higher implementation costs than were expected, (ii) short term lower quality manufacturing, (iii) incorrect product specifications, (iv) short term lower customer satisfaction and (v) quicker competitive adoption of the technology.

The difference between these 'promises' and the 'realities' of the new technologies can best be understood through the number of unexpected problems incurred through the introduction of new technologies, where: (i) unexpected policy issues, (ii) technical problems or (iii) incompatible technical operations dominate. For I.C.L. Kidsgrove, the demands of being a centre of excellence for advanced Printed Circuit Boards (PCB's), means that its manufacturing operations are continually subject to these problems associated with the continual process of technical change. This occurs because I.C.L's desire is to achieve the specific aim of being a 'market leader' in PCB design and manufacture. This is particularly apparent in the progressive technical evolutions of: (i) the automation of PCB manufacture, (ii) the enhanced multi-layer PCB techniques, (iii) the increasing number of board layers and (iv) the smaller through-hole sizes needed in the PCB's. The effect of these requirements is that they dictate the means by which the technologies have to be adapted to accommodate: (i) smaller track widths, (ii) higher precision drilling and plating and (iii) even more advanced material technologies (International Computers Limited, 1986).

At I.C.L, Kidsgrove, a classification of the types of technical change and the problems which can be associated with them are identified from four particular areas in the Manufacturing and Logistics site. These four areas are: (i) the product design stage, (ii) manufacturing operations, (iii) the design/manufacture interface and in (iv) future systems designs. Within these four areas, technical changes are illustrated by two particular types of technology: (i) in new technical products and in (ii)new technical processes. These new technical developments are produced in three areas either: (i) inhouse experimentation, (ii) interfirm cooperation or (iii) dictated by external influences, and are determined by their technical, commercial and financial viability. I.C.L assume that any change in one or all of these functions constitutes a particular type of technical change.

From the identification of these types of technical changes which take place at I.C.L Kidsgrove, an evaluation process could be conducted between these practical descriptions of technical change and the structure and functions of the viable system model of technical change.

7.31 A Needs Evaluation

This particular needs evaluation assesses the possible application of the viable system model of technical change to the practical examples of technical change identified at I.C.L Kidsgrove. To identify this need, an assessment of the consequences of technical change in relation to the activities at I.C.L was carried out in order to determine how the structural and functional framework offered by the viable system model might fill an applicable need.

7.311 The Impact of Technical Change at I.C.L

From the information from the three areas of: (i) manufacturing, (ii) design and (iii) future systems, the specific consequences of technical change were determined for a multiplicity of reasons. These ranged from, the impact of changes in skill requirements of employees, to specific technical support problems. In all direct responses from the interviewees, it was identified that the principal consequences of technical change at I.C.L is determined by the direct relationship between I.C.L activities, and the management of its association with its customers. This impact is not only whether the customer can accept the speed of technical changes, but whether the change is in their customers interests, and how the technical changes can strengthen the existing relationships as well as add to them. Technical change at I.C.L concerns two additional areas: (i) a marketing function and (ii) the organisation of I.C.L's operations.

Faced with increasingly rapid advances in technical developments, one of the key problems for I.C.L is how to determine the means by which a reduction in the time it takes to move a new product concept onto the marketplace can be achieved. This is the critical aspect of technical change on the current activities of I.C.L (Dimond and Ellis, 1989b). The implication of this, from an I.C.L, Kidsgrove viewpoint, is to recognise that technical advances cannot be adopted without changes elsewhere in the organisation. This produces two requirements: (i) an infrastructure which can be used to adopt and add value to new technical developments by utilising tools, libraries and existing operational information to provide the most effective means for implementing technical change, and (ii) the identification of the necessary activities through which an effective process of technical change can be achieved. With respect to this, I.C.L have emerged with some initial, if somewhat tentative, conclusions concerning an organisational structure which attempts to accommodate new technical developments and hence, reduce the 'time to market'. These refer to aspects of a customer focussed organisation, rather than project focussed, which are solely used to remove the high inertia, highly bureaucratic aspects of a functional organisation (Saxl, 1989).

The focus of the consequences of technical change on the marketing function reflected a major concern that communication channels between the activities in: (i) marketing, (ii) design and (iii) manufacture should be made clear and unambiguous concerning the consequences of technical changes. The need was to identify the necessary functions involved in technical change within these areas and provide an effective communication structure by which information regarding the functions associated with technical change could be disclosed to other operations in I.C.L.

7.312 The Need for a Viable System Model of Technical Change at I.C.L

The consequences of technical change at I.C.L provide two general characteristics: (i) opportunities and (ii) problems. The viable system model of technical change provides an appropriate framework through which the process of technical change at I.C.L may add value to the firm. In addition, the viable system model introduces a functional framework within which the dependent relations between the function may provide some insight into the necessary communication requirements if a successful process of technical change can be achieved. It is through these particular needs that the viable system model of technical change can be of use to the current activities at I.C.L Kidsgrove.

The next section is used specifically to evaluate the current practice of technical change at I.C.L by using the viable systems model of technical change. A formative assessment is used to determine how this viable system model can help clarify the current activities of I.C.L in relation to technical changes.

7.32 A Formative Evaluation

This formative assessment uses criteria in which both the functions and structural framework, described in the viable system model of technical change can be evaluated in relation to interpretations of technical change as identified at I.C.L. The aim is to examine the applicability of this viable system model in the business oriented context of technical change, by identifying the particular areas of significance of technical changes in relation to the model. The criteria is based upon the five system functions and their dependent relations. Each system is evaluated in terms of its activities, structure and dependent relations, with respect to the practical interpretations of technical change.

7.321 Practical Systems of Technical Adaptation

The structure and function of a System One in the viable system of technical change is based on the activities associated with technical adaptations. In this formative assessment, these characteristics of a System One are evaluated with technical adaptations identified at I.C.L. These adaptations are defined as: (i) product technology developments and (ii) process technology developments. In addition, these two forms of technical adaptation take place in the business centres of design and manufacture.

At the design stage, new product technology developments are produced through a process of multiple iterations of PCB artwork which ultimately produces a validated new product technology design. In these new designs, I.C.L generally incorporate either: (i) a new product design structure of existing component technologies and/or, (ii) introduce specific types of new component technologies into the design. At this design stage, any new product developed focuses on three aspects of the component technologies used, and as a result, these control the nature of the product development. These local design controls used on new technical developments include: (i) structural aspects. These are used for small components to identify and control the logical function of the components in terms of time and compatibility, as well as making sure all components are actively functioning. (ii) For the medium sized components, the control mechanism is a 'behaviour' oriented function. That is, it analyses the particular waveform produced from the components using the appropriate test data. (iii) The third mechanism is a hardware control. This is used to regulate the effects of the new large components in the design structure, where the actual component technology is assessed by using various input patterns and observing the information output.

These new product technology developments in the design business centre tend to be driven by the list of available component technologies, and generated by material purchasers. In many cases, designers rely on a two way relationship between themselves and material purchasers to identify new technical components obtained from the numerous component suppliers, rather than through direct manufacturing communication. However, the lists used by the manufacturing business centres contain different information regarding these component technologies. As a result, a number of successfully developed product and process technologies in the design business centre appear to fail in the manufacturing business centre.

These two types of technical change: (i) product and (ii) process technical developments which are found in the design stage, filter through into the manufacturing process. Yet in manufacturing, there are other new technical developments. These technical changes occur at a much slower rate than new technical developments in the design business centre, principally because these technical developments are driven by the existing manufacturing process. Technical developments in the design business centre are always customer product driven. For example, whilst bare board technology changes in I.C.L products have been quite dramatic in recent years, the changes within the process of its manufacture have been less so. Although new technology designed into the bare boards has allowed for finer and finer tracking, the actual technology which can achieve this tracking in the manufacturing process tends to change at a much slower pace. Possible reasons for this is the current relationship between technical adaptations in the design and manufacturing business centres. This is due to two factors: (i) the investments involved in the existing manufacturing process technologies require a long term technical life span, or (ii) the particular technology may not yet be commercially available. One of the consequences of this is that the general technical adaptations which occur in the manufacturing business centre tends to drive the technical developments within the design business centre. The reason being, that if the new technical designs can not be manufactured, then the designs are useless.

In general, the existing technologies in the manufacturing process consist of three particular technical operations. These are categorised as: (i) surface mount technology, (ii) auto-assembly technology and (iii) manual insertion using technical support. In 1989, surface mount technology accounted for approximately 20-30% of the total manufacturing process at I.C.L's Manufacturing and Logistics site. For manufacturers the ideal would be to create a technical change process in surface mount technology in the manufacturing process which would enable the total manufacturing process to operate using 100% surface mount technology. However, whilst local controls are used to generate this type of technical change, current activities at I.C.L indicate that such technical changes would produce a fully technically compatible manufacturing process, but would also produce a pronounced limitation in the areas of: (i) product flexibility and (ii) design functionality desired by I.C.L customers. Whilst the local controls regulate new technical developments, they are also controlled by the direct influence of the activities of the customer rather than on a specific strategy of technically optimising the manufacturing process.

These descriptions of technical adaptations in the design and manufacturing business centres do indicate that there is some form of structural relationship between the primary function of adaptation. The particular structure creates a number of problems which I.C.L acknowledge: (i) technical developments in design are inevitably constrained by the technical developments in manufacturing, (ii) the local regulators in manufacturing technical developments create unnecessary constraints on other functions within I.C.L and (iii) the interaction between technical developments in the design and manufacturing business centres creates an instability which leads to a longer 'time to market' than desired.

The viable system model demonstrates a structural and functional similarity with the current operations which produce technical adaptations at I.C.L. In particular, the relationship between the technical developments and the local regulators which monitor the application of the changes. Whilst the current activities are not explicitly structured in terms of the viable system model of technical change, the implication is that the structure presents a means by which the successful preparation for technical adaptations can be made.

The activities of technical change identified in both the design and manufacturing business centres, interact to produce instabilities which generally produce a longer than expected 'time to market'. To evaluate how and why this instability occurs, and to assess how the viable system model of technical change might be able to explain these instabilities, and present an appropriate structure to reduce them, is discussed in the following section.

7.322 Systems to Remove Instability in Technical Adaptation

The identity of instability emerging from the interactive activities between the design and manufacturing business centres, provide the basis of a second formative assessment of viable system model terms of technical change. In general, the evaluation aim is to find out the structural aspects of any I.C.L system which is currently designed to reduce these instabilities, and to assess the correspondence between it and a System Two within the viable system model of technical change. To evaluate a System Two in the viable system model, the criteria is based on three considerations: (i) an explanation of how technical instability is created at I.C.L in terms of any existing structure, (ii) to identify current mechanisms used to reduce this instability in relation to System Two and (iii) to indicate how the function of a System Two may provide an appropriate means by which the reduction of technical instability at I.C.L can be achieved.

The apparent consequences of technical change within each of the design and manufacture business centres, indicate that a particularly strong area of instability generally exists when the effects of the technical change move from one business centre to another, that is, at their interface. To control this aspect, the current mechanism used in I.C.L operates in an attempt to produce an information compatibility between new technical changes in the design business centre with any new technical developments in the manufacturing business centre. This is generally achieved by transferring the design language, which reflects the new technical developments, into a language corresponding to the technical activities in the manufacturing process. This design language is modified by three activities, these are: (i) developing a library layout which in turn produces (ii) an Information Design File (IDF) consisting of a temporary definition of the PCB technical parts and components and (iii) Gerber (digitised information for the manufacturing process) information concerned with the design structure and drill information. This design information is used to create a definition of the design in terms of its implication to the technologies operating in the manufacturing process, which provides a validation of whether the new technical design can be manufactured. If this is accepted, the manufacturing definition of the design is used to produce: (i) an auto-assembly sequence, (ii) a manual assembly, (iii) set up information and (iv) process planning. Figure 7.2 describes the current control system structure operating at I.C.L.

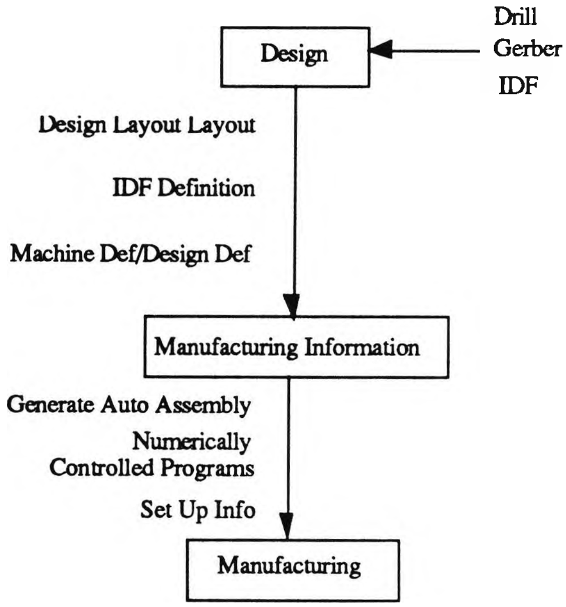


Figure 7.2 the current control mechanism operating at the interface of the design and manufacturing business centre

Although this control system structure removes some unstable characteristics, instability remains a current and undesirable feature at this interface of the design and manufacture business centres. This commonly results in problems of incompatible information between current manufacturing ability and design definitions. The effect in design is generally seen by the use of inappropriate technical components as expressed in manufacturing language.

For example, I.C.L designers developed a new PCB design using new technical components. This required both auto-assembly and surface mounting technology in its manufacture. The designers assumed that the rules associated with these two manufacturing technologies were identical, as the I.D.F only reflected design assumptions concerning the manufacturing process. The consequence of this new design was that the manufacture of it was repeatedly unsuccessful (approx. 4 months). Manufacturing continued to think that the new technical design contained a hidden error, whilst designers continued to assume that their new PCB design was accurate. The technical instability which resulted from this change caused a lengthy problem solving procedure, and led to further problems elsewhere in the manufacturing process and in other new designs which also incorporated the new technical components. In addition, this instability created problems with I.C.L's customer base, which according to I.C.L, should not have been a problem in the first place. The implications from this example highlights one of the key problems in such a process of technical change. Once the new technical design was pushed through into manufacturing it was impossible to know whether its manufacture was 'perfect' until the end of the manufacturing process. This corresponds to high cost manufacturing.

A second source of instability was identified as a direct result of the flow of information concerning new I.C.L products between the design and manufacturing business centres which was not always complete. This was mainly due either to incorrect information, or that the information was unknown. Where information could be obtained, the design would not be manufacture validated because of this incomplete information. The instability emerged from this additional time length required by manufacturing to access and retrieve information between the design and manufacturing stages involved in the technical changes.

Acknowledging these current difficulties, I.C.L have proposed a new control system to damp down these areas of instability caused by the consequences of new technology. This will be achieved by introducing three key changes to their control system structure operating at the design and manufacturing business centre interface. These include: (i) a new form of design definition, (ii) an assessment concerning manufacturability and (iii) a new definition on the manufacturing process. In addition, the introduction of an Issue and Archive DataBase (IADB) as a common information source for the design and manufacturing business centres is hoped to provide a critical and effective service, for the access and retrieval of current information which is absent within the present control system. Control will be achieved by assessing the capability of new manufacturing technology and its compatibility with new PCB designs and the PCB designs which incorporate new technical components.

However, the new control system, whilst not currently in operation, is recognised at I.C.L, as likely to produce a control system structure which damps technical instability by being manufacturing led. The assumption being that designs cannot be accommodated unless the capabilities associated with its manufacture are present. To initiate a design led system, the requirement is for a second addition to the control system structure. This should define a feedback mechanism to operate between the design and manufacturing business centres. Figure 7.3 illustrates the structure for this new control system.

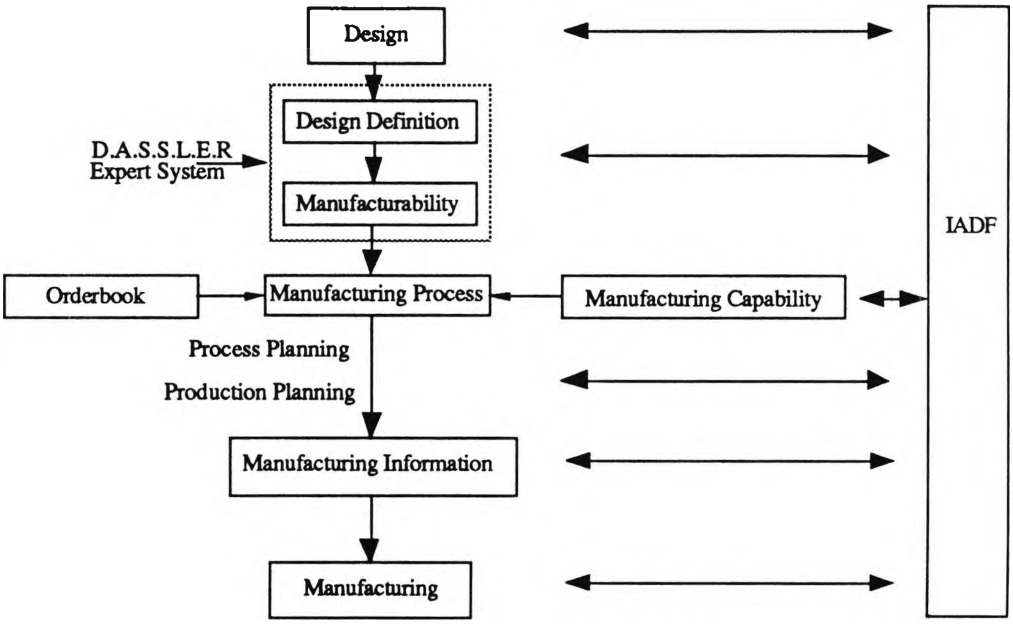


Figure 7.3 the structure of the proposed control system for new technical instability

Other areas identified as containing instabilities resulting from technical changes were: (i) within the design business centre and (ii) in the manufacturing business centre.

In the design business centre, instability is most apparent when new PCB designs also require new technical components. In some cases the new technical components supplied, vary in their high degree of compatibility with the overall PCB design because of the different speeds or capacities used within the same technical component, but supplied by a different manufacturer. The effect is that the new technical components have to be continually tested, and this inevitably leads to a longer time interval between PCB design and manufacture. Control of this instability does lie outside the design business centre and depends on the communication links with the material and stock handling business centre of I.C.L.

Within the manufacturing business centre, the problem of instability generally involves the introduction of a new technical product into the existing manufacturing process which requires additional technical adaptations to that process. For example, in the manufacture of a bare board, the first stages usually involve the production of drill holes and the creation of a bonding thickness onto the board. The current practice is to to (i) physically inspect, (ii) move the bare boards and (iii) laminate them with light sensitive firm in order to expose them to ultra violet light. A subsequent electro copper/tin/lead plating process is used between the holes and pads in the board. Through the introduction of a new technology concerned with the computerised visual inspection of the bonding thickness and the results of drilling, this inspection technology provides the potential of a fully automated manufacturing process which can utilise new PCB design in the manufacturing business centre. However, the instability this has caused, was to effect the geographical location of the existing technologies in the manufacturing process, and also to distort the overall timing of the manufacturing process so that different batch sizes had to be used in order to accommodate the new technical product and provide a compatibility with the existing processes. The implication was a slower process in the construction of the bare board, yet this was technically compensated for by the reduction in the failure rates of bare board manufacture after the initial introduction period of the technology.

The findings of this formative evaluation of a System Two produces three particular aspects: (i) the instability involved in technical change tends to emerge when the consequence of the technical change is passed onto another activity, as in the case where the implications of technical development is carried from the design to the manufacturing business centre. This explanation is provided by an analysis which uses aspects of the viable system model of technical change to define the structure associated with these instabilities. (ii) I.C.L acknowledge that it is a necessary condition to reduce these instabilities by introducing a specifically designed control system structure. The existing structure is identified by I.C.L as inappropriate to their current requirements because the effective reduction in technical instability is not provided by the system. The new control system is dominated by a manufacturing led assumption of technical developments. The problem here is that technical developments in manufacturing are assumed to change at a much slower rate than in technical designs. The implication is that such a control system would not be able to provide any effective reduction in the 'time to market'. (iii) The function of System Two is defined by the activities of coordination, whilst this is achieved in the control system proposed by I.C.L, the structure of a System Two indicates that a more effective control system might be introduced which contains a feedback activity, between the design and manufacturing business centres.

Other findings from the assessment indicate that technical instability in one particular business centre can also be associated with technical benefits in others. This consequence illustrates that the process of technical change required a knowledge about the overall effect of the instability in the manufacturing operations on the total operation of I.C.L. There is a need to evaluate additional aspects of technical change with the other functions and remaining structure identified in the viable system model of technical change.

7.323 Technical Selection at I.C.L

A System Three is structured so as to provide the necessary self-regulatory activities for viability. In the viable system model of technical change this structure is associated with the selection mechanisms used in determining the outcome of competition between different technologies. This third formative assessment is used to evaluate this proposed system in the viable system model of technical change in relation to the activities identified at I.C.L. The criteria by which this assessment is made is twofold: (i) to identify the particular activities associated with the process of new technical selection at I.C.L and (ii) to identify any structural and functional similarity between the activities of technical change at I.C.L and a System Three. The general aim of this assessment is to identify the activities used in the selection of new technology, both in the design and manufacturing business centres, and to illustrate how a System Three structure might provide a more appropriate framework for technical selection within the process of technical change.

Within the context of I.C.L's current operations, the selection activities are identified primarily through financial considerations, and this is principally based on information derived from: (i) existing activities within each business centre, (ii) from environmental knowledge derived from various market and (iii) other business oriented reports. The first means of selection is classified as being driven from the 'in-house' business centres, and in such cases the costings of a new technical product or process are selected by the individual business centres in I.C.L. In the manufacturing business centre, the manufacture of a new product would be costed in terms of the effects on: (i) changing production techniques and (ii) the costs of production. In the marketing business centre, the cost of the new technology would be linked to its effects on the proposed market, such as: (i) the size of the market and (ii) the necessary discounts to enter the market. Through a second means of selection, the concept of the new technology is assessed by a specific development group which initially generates an approximate cost outline based on current manufacturing, market forecasts and other applicable costs. Whether, the technical change is in new product or new technology, a financial selection process appears to be performed at every possible stage of analysis.

This information illustrates that the activities involved in technical selection, can be classified into two particular types:

(i) Technical selections which are primarily concerned with manufacturing. For this type, comparative costings generally cover the useful life of the technology, and incorporate aspects of: (a) book values, (b) the cost of repair and (c) reliability costs.

(ii) The second type of technical selection can be done in parallel with the first type, but generally covers new product developments or new component technologies in the design business centre. Two stages are involved: (a) a general statement of intent and (b) a financial proposal. The statement of intent embodies four characteristics. These are concerned with, the financial background, a financial proposal, implications and alternatives. The financial background covers a general economic statement of the concept The financial proposal follows this statement, and identifies both technical information and the estimated total amount of capital involved. The implications of these financial aspects concern the economic means for implementation and this is usually reflected by the changes in the cost of material requirements, and in wage cost changes. The the overall financial benefit is then classified in terms of: (a) cost, (b) efficiency, (c) safety and (d) product quality. This leads to a financial analysis of alternatives in terms of technical effects on the marketing, design and manufacturing business centres.

Having established this financial statement of intent, the financial proposal is used to determine the selection of the appropriate new technologies. This proposal is a detailed analysis of the cost to the various business centres and the economic returns expected. Having got through to this stage, the prospect of selection is firmly based upon the current budgeting constraints of I.C.L. If a technical selection is achieved, the proposal provides the basis of the project budget, and is then used to determine a profit and loss analysis, using various parameter changes in: (a) depreciation factors, (b) interest rates and (c) technical lifespans.

Financial selection occurs at every level of technical change within the current activities of I.C.L. The two financial controls concerning technical changes operate within the design and manufacturing business centres solely as a means of technical selection. At the managerial level, the selection of new technologies does tend to be led from the economic implications of the manufacturing function. This illustrates a degree of control over the selection of possible new technical opportunities within the design area.

From these observations concerning the current activities of technical selection at I.C.L there is, at this level of analysis, a similarity to the functional aspects associated with a

System Three. These activities are determined through economic costings rather than on the human structure surrounding technical operations because, not only are labour costs approximately 2% of the total cost, material costs account for approximately 80% and a large percentage of the remainder covers the technical costs of operation. The employee structure is firmly based in a supporting role to the technical activities, and therefore, the economic costing of particular technical developments is seen as the determining force for technical change at I.C.L. The structural framework in which these activities of technical selection occur is conditioned by the business centre philosophy of I.C.L. As a consequence of this technical changes are assessed in terms of: (i) being commercially prudent and (ii) financially viable within each business centre.

The structure of System Three indicates that technical selection should also be based on the particular functions of: (i) control, (ii) coordination and (iii) direction. The current financial selections conducted by I.C.L. offer only a controlling function. The financial controls should also be used to coordinate and dircct particular activities within the design and business centres and also use the information inputs and outputs from the control system structure between these two business systems. At present I.C.L felt that there was little application for the financial selection process other than through its use as a controlling function.

7.324 System Four and the Anticipation of New Technology at I.C.L

A System Four in the viable system model of technical change is defined as an anticipation function, structurally linked to the viable system environment, with the functions of selection and identity. In this formative evaluation, the structure and function of System Four is assessed in terms of the forecasting activities of new technology identified at I.C.L. The evaluation of a System Four structure and function is based on three criteria: (i) I.C.L's general approach to anticipating new technologies, (ii) the use of a model to present an overall description of the operations of I.C.L in relation to technical change and (iii) activities which utilise measurement characteristics in I.C.L for anticipating new technologies. These criteria which are used to evaluate a System Four are primarily linked to the activities of the Advanced Information Systems Group, a part of Advanced Systems Development, which in turn is organisationally linked to the Future Systems business centre.

The Advanced Information Systems Group is organisationally classified as a support service to the manufacturing operations of mainframe and personal computer technology at I.C.L, Kidsgrove. Its function is to identify, design and develop technically based tools and techniques which can be used throughout the manufacturing process to improve current operations. In this respect, it operates 'inhouse', by identifying and defining business problems and opportunities which can be dealt with through the introduction of new technologies, in order to create 'complete solutions' for these areas. It achieves this through two central mechanisms, these are: (i) as a business led and (ii) as a technology led service.

As a business led operation, Advanced Information Systems is used to increase business awareness to the potential of new technologies. This is achieved through an analysis of demand forecasts concerning current operations and product overfulfilment. It also investigates how new technologies might alleviate existing problems or produce added value in the business centre areas of: (i) manufacturing, (ii) design (iii) purchasing and (iv) software development.

As a technically led support service, Advanced Information Systems main function is to introduce, to the general area of manufacturing operations, new technologies which appear to present new opportunities. Although analysis of the technology is undertaken within Advanced Information Systems, the current practice is to feed the technology into the manufacturing or design business areas in order to increase awareness of the new technology.

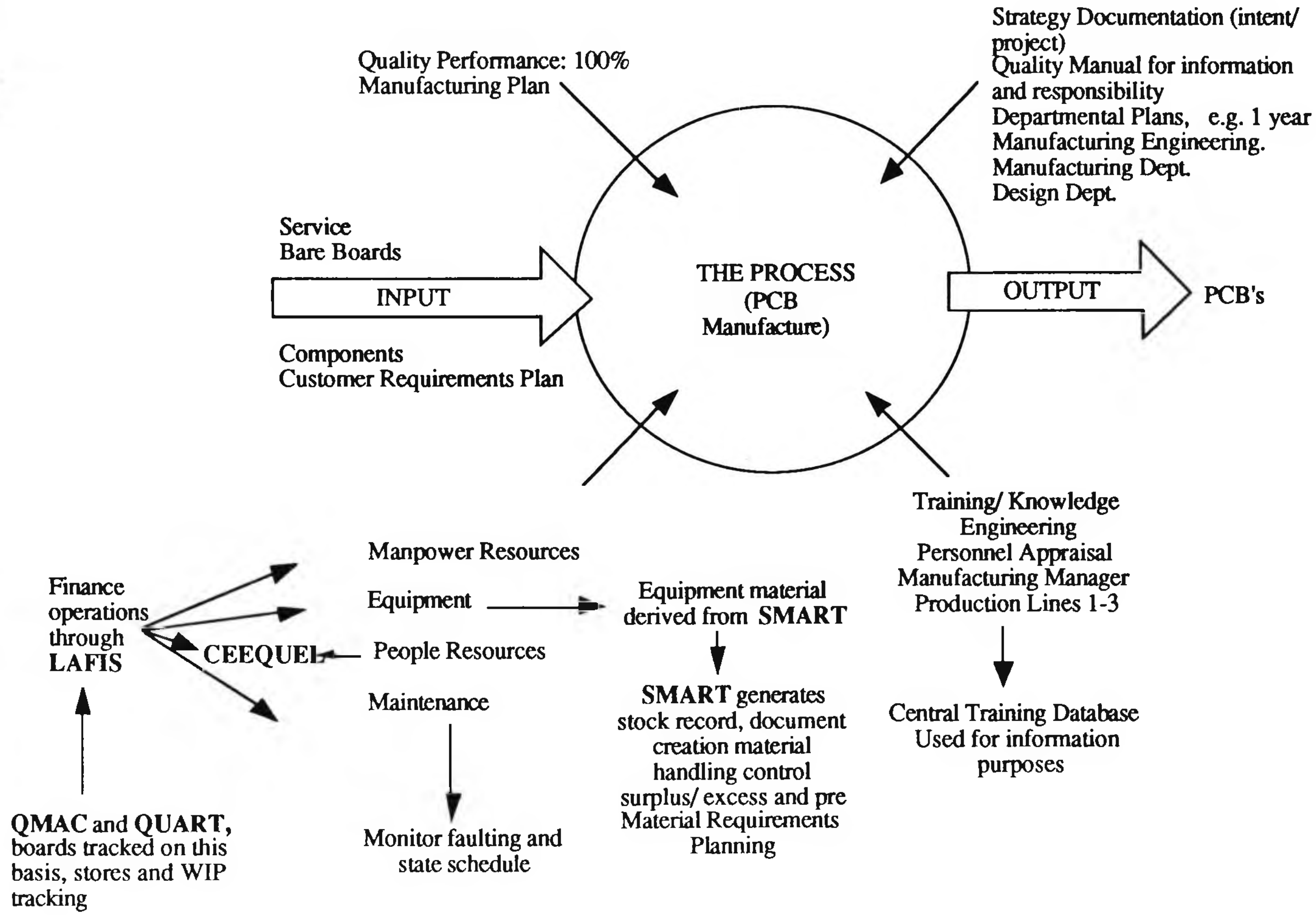
As a consequence of this duality of roles for the Advanced Information Systems Group, the function of technical anticipation is in almost continual conflict between the achievement of performance improvements and economic benefit. One of the problems of being technically driven is that if the competition utilises the new technology first, I.C.L loose the competitive advantage it may have gained, and any subsequent economic benefit from it. But in other aspects, the adoption of a new technology in one area is often accompanied by a vagueness in other areas on what the technology can actually do specifically for current operations.

The problem with the introduction of new technologies into current operations, is that although it increases awareness of the new technology, as it can be more readily visualised, the general tendency is for the technology to remain in a dormant state in the operational areas. In a recent example, Advanced Information Systems had analysed the possible implications of using expert system shells in 'shop floor' operations. As a consequence of this, a number of these technologies were passed into manufacturing in order to increase the awareness of the new technology and present possible applications for their use. The current assumption for this activity was that once the technology had been passed to other business centres it was up to each business centre to define its technical use. The results indicated that each business centre were able to observe the new technology, but were unable to define a use because they were unaware of its potential. The expert system shells were eventually returned to the Advanced Information Systems Group simply because the information of the effects of the new technology had been inadequately transmitted to the other business centres.

For the Advanced Information Systems Group, the problem of technical anticipation is concerned with whether new technologies are actually necessary both technically and economically. The tendency at present, is to learn from: (i) past failures and (ii) competitors actions. From these two criteria it is assumed by the Group that it is possible to learn how to derive a profitable return from investments in new technology by the actions of competitors and learning from their mistakes.

Whilst the expertise in anticipating new technologies 'inhouse' is derived from the Advanced Information Systems Group, two other areas for technical anticipation derive from associations with particular institutions. These are (i) based on an academic foundation, particularly with the Artificial Intelligence Applications Institute and, (ii) derived from commercial sources, such as, research companies associated within the area of neural networks. Although these two areas of expertise produce relevant information concerning new technologies, it is the function of Future Systems as well as Advanced Information Systems and Advance Systems Development to anticipate the implications of the new technical information from these sources.

Within these current operations, I.C.L rely on a general model of operations at I.C.L, as the basic framework for generating a new technical concept into the manufacturing and assembly process of PCB's. This process model of PCB manufacture and assembly is the most widely used model by which any analysis can be undertaken. Within the current function of technical anticipation, the model is used simply as a descriptive device rather than as an explicit means of determining the effect of new technologies on current operations. The response from Advanced Information Systems to the use of such a model to assess the implications of new technical anticipation was seen as: (i) superficial and (ii) an unwarranted requirement. This was because their anticipatory function was assumed to be one which only led to increasing awareness of new technology for operations in other business centres. This model is represented in figure 7.4, and indicates how I.C.L, Kidsgrove, currently perceive the process of PCB manufacture in what can be classified as an open system model.



Key

LAFIS, CEEQUEL, QMAC, QUART, SMART: Identified information systems currently used in supporting technical changes

Figure 7.4 the open system model of the current technical activities at I.C.L, Kidsgrove

The Advanced Information Systems Group do not use any particular measurement format to forecast new technical developments. The idea that measuring can provide a reduction in the uncertainties surrounding the anticipation of new technology was assumed to be unwarranted. This was because the Group assumed that the impact of technical change through the anticipation function should be pushed on the the user or business centre, rather than be defined by the Groups own particular activities.

In the other business centres measurement of the effect of technical change is conducted. In the design business centre six particular measures determine the acceptability of new technology, whether in terms of new technical components or in new product designs. Whilst the design area is controlled by technical improvements in manufacturing, designers attempt to derive a new technical hardware CAPABILITY measure in order to create a link with current design rules, and defined by the designers as measures of current practice. In addition, new product designs dependent on new component technologies are often measured in terms of component AVAILABILITY, in order to reduce possible delays in manufacturing the new product design. Other more specific measures relating to the technical change are concerned with CONNECTIVITY and COORDINATION measures which determine new technical COMPATIBILITY and a FUNCTIONALITY measure which details the extent of possible applications for the new technology.

Measurements in the manufacturing business centre are linked to an analysis of technical change which concentrate on criteria within the production line and the product introduction process. The main measures include, a product line efficiency measure, hours to manufacture and a quantity or product availability measure. Measures describing current production capacity, frequency of production change, manufacturing capability and a proposed manufacturability measure all have the potential to provide insight into the impact of new technology within the manufacturing business centre.

The financial business centre utilise a number of measurement in relation to technical change. These include: (i) the effect of budget constraints, (ii) obsolescence rates and (iii) salvage values. They are used to generate a financial capability measure for the introduction of further new technologies. This indicates a financial link to the prospect of technical anticipation in terms of identifying whether the new technology should be adopted 'inhouse' and passed into a selection process, or monitored through external contacts, such as in academic or other commercial institutions.

The formative evaluation, I.C.L utilise a number of activities to provide the function of technical anticipation. This is identified in the activities of the Advanced Information Systems Group. They include both 'inhouse' experimentation and commercial links with specific research institutions. Whilst a model can be identified within the overall operations of I.C.L, it is not utilised to provide a more informed assessment of the anticipation of new technologies. The measures used to identify the implications of new technology are located within the each business centre of I.C.L rather than in the specific activity of technical anticipation.

The findings illustrate that there is a high degree of similarity between the function of anticipation used in the Advanced Information Systems Group and that identified in a System Four. This includes: (i) a specific link with the environment containing future technical possibilities. This is monitored through (a) 'inhouse' experimentation and (b) commercial links to specialist organisations. (ii) There is also a link to the other business centres of manufacturing and design, although the specific needs of the manufacturing business centre are dominated by the activities of the Advanced Information Systems Group.

The structural framework of System Four does reveal that I.C.L can increase its anticipatory activities in the following ways: (i) to link the model of the operations at I.C.L with the measurement already conducted in the various business centres to provide a more coherent analysis of the possible effects of new technologies being introduced to the various business centres. (ii) By linking these aspects specifically with the function of technical selection may provide a mechanisms whereby the possible reduction in time lags in adopting a particular new technology may result. This might also lead to a definition of more accurate solutions to current problems and opportunities through a structured framework coordinated the effects of technical anticipation. (iii) That the general aim of the Advanced Information Systems Group should be changed from the identification of new technical opportunities to a wider technical anticipation capacity.

7.325 Technical Identity in Manufacturing Operations at I.C.L

The final assessment in this formative evaluation is based on the functional and structural framework of a System Five which is linked to the technical change activities at I.C.L. The criteria used in this assessment concerns: (i) the functional aspects and

(ii) the structural framework of a System Five, and focusing on a possible I.C.L. relationship between the financial selection and the anticipation of new technology.

The only identified link between these two functions of selection and anticipation as defined through the finance business centre and in general terms, the Future Systems business centre, is provided by a market driven control mechanism. This control mechanism operates by comparing current consumer requirements with what is currently available to I.C.L and what may be technically possible. In this manner, new technical possibilities are controlled by the extent of possible competitive advantage and by the potential added value offered by the new technologies.

The critical problem within this area concerns the process of adapting the current technical identity of I.C.L to meet future technical styles emerging within the microelectronics industry. This is reflected by I.C.L's existing organisational emphasis on a business centre philosophy. Because of this philosophy, the identity of technical change presents a different meaning within each business centre, and overall this creates a technical vagueness over: (i) who owns the technologies and (ii) what type of technology should be used within I.C.L. The implication from this is a confusion over having the ability of adapting a technology in a business centre and the potential implications of such as change in other business centres.

The technical identity is also subdivided within each business centre into four principal areas. The manufacturing centre, which was the central focus of this practical evaluation, defining a current technical identity in terms of support, strategic, operational and future possibilities. From the results obtained, the most effective means of changing the technical identity of I.C.L is to move as rapidly as possible from a technical possibility to support operation technology, either through a customer or technical driving force. In terms of manufacturing operations the process of technical change is more difficult in the transition from what is defined as a technical possibility to a support or strategic technology, because of the implications of the market driving mechanism. A change in identity is classified by changes within the subdivisions defined through a customer or technical orientation.

These findings provide an indication as to the identity of technical changes at I.C.L. This functional similarity of a technical identity is carried through to a degree with the market control mechanisms operating on the functions of technical selection and anticipation. The reliance on the business centre philosophy does create a particular problem in this respect. This is because within each business centre each technical change is considered independently of other business centres, this means that the transfer of technical activities to other business centres create an uncertainty as to: (i) whether it should be done, (ii) the cost which should be paid for the technology and (iii) the financial implications to the business centre.

System Five does provide a clear indication as to how the structural and functional framework should operate. The current problem can be defined as one which illustrates a confusion amongst technical change recursions. That is, a System Five should operate within each business centre, rather than relying on an overarching I.C.L technical identity. By introducing at least two levels of recursion into I.C.L's structured approach to technical change, a reduction in this vagueness regarding certain aspects of technical changes can be achieved.

This concludes the formative evaluation of the viable system model of technical change to a practical example illustrated through the activities of I.C.L. The final stage of the evaluation now considers the viable system model in terms of the types of technical change which are identified in the activities of technical change at I.C.L.

7.33 A Summative Evaluation

The summative evaluation is used to assess the viable system model of technical change with known types of technical change identified in this practical example. By evaluating the overall configuration in relation to the five system functions and structure, a comparison is used between these aspects of the viable system model and known types of technical change, to provide a comprehensive assessment of the viable system model in relation to technical change in practice.

7.331 Types of Technical Change at I.C.L

I.C.L do not readily identify with particular types of technical change within the microelectronics industry. The most common format for discussing technical changes tends to focus on a four grid matrix reflecting the introduction of: (i) support, (ii) strategic, (iii) operational and (iv) future technologies or the transition between two of these technologies as identified in figure 7.5.

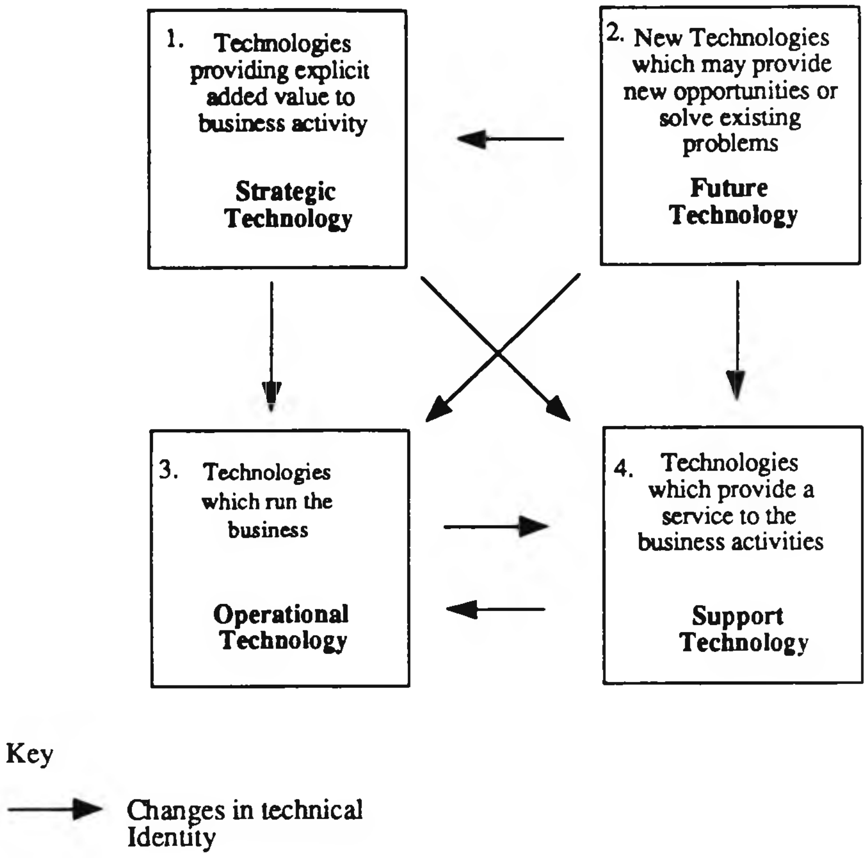


Figure 7.5 Identity definitions of technical change at I.C.L

The grid indicates two particular types of technical change: (i) new technology introductions, and existing technical transitions-technical evolutions. The following section discusses the structure and function of the technical changes at I.C.L, in relation to the viable system model of technical change.

7.332 The Configuration of Technical Changes at I.C.L

The findings from the formative evaluation describe how I.C.L's approach to technical change compares with the functions and structure of a viable system model of technical change. The definition of the overall configuration is based on identifying the structural linkage operating between the system functions. For I.C.L the problems of defining a structural linkage is caused by its reliance on a business centre philosophy in the areas of manufacturing, design, finance and future systems. In this respect the structure and function of the activities associated with the type of technical change do not function according to the framework presented in the viable system model of technical change. In this respect the same function and structural configuration is used with: (i) the introduction of new technology and (ii) the evolution of existing technology.

As the question of technical change is concerned with overall company effectiveness, new technologies are currently determined by the individual technical needs within each business centre. For evolutionary technical changes, such as the transition from the strategic manufacturing technology of surface mount technology to a more operational role, this should be achieved within the functions of System One and System Two rather than by introducing the other functions of selection, anticipation and identity as well.

With the introduction of new technologies, the viable system model framework, provides the structural framework for the five system functions. In this respect, the new technical introduction indicates a variety increase within the activities of technical change. For the viable system model, this implies: (i) a possible manipulation of recursiveness to accommodate the new technology and (ii) compatibility changes to the existing technical adaptations within I.C.L.

The viable system model provides an appropriate and useful description for these types of technical change which take place at I.C.L. Whilst it is evident from the formative evaluation that many of the system functions in the viable system model can be identified in the operations of I.C.L, there is no clear structural framework with which the types of technical changes are classified. This viable system model of technical change provides for a reinterpretation of the types of technical change expressed at I.C.L. In addition, the model also presents a functional and structural framework by which a viable process of technical change can take place using existing activities identified in the various business centres.

This concludes the findings from the summative evaluation between the types of technical change which occur at I.C.L and the viable system model of technical change. The following section considers the conclusions concerning the viable system model of technical change which can be derived from the findings of the three stages of the evaluation process.

7.4 Conclusions

Does the viable system model of technical change provide a comprehensive account of technical change in practice? The three stages of the evaluation process which were conducted on the viable system model of technical change to the practical examples identified at I.C.L, offer the following conclusions which can be used as a comprehensive answer.

(i) Technical change in practice illustrates two general characteristics: (a) opportunities which add value to the activity of the firm and (b) problems which create poor performance in the firm. I.C.L acknowledge that there is an explicit need for an appropriate framework in which the opportunities offered by technical change can be exploited, and a framework which reduces the potential of poor performance from the introduction of new technologies. The viable system model of technical change was considered to be an appropriate mechanism which offered two particular aspects: (a) specified functions and (b) a structured framework for technical change.

(ii) The viable system model containing its five system functions and dependent relations provides for a significant and positive reinterpretation of technical change at I.C.L. In particular: (a) it provides a functional and structured framework of the practical system of technical adaptation operating within the two business centres of design and manufacturing. (b) The dominant use of a control system structure in the operations of technical change at I.C.L, illustrated the importance of a System Two structure within the viable system model of technical change. This was identified as a means to reduce instability, and that, importantly, the current approach could not effectively damp this instability. The structure of a System Two illustrated the need for a feedback structure which linked with the function of coordination, rather than through direct control. (c) System Three was described in the activities of technical change at I.C.L through a financial selection mechanism in the activities of design, manufacturing and strategy. (d) The function of a System Four as an anticipatory mechanism was identified in the Future Systems Business Centre, particularly at the Advanced Information Systems Group. The structure provided a indication as to how the anticipation of new technology might be more effectively conducted. (e) A System Five illustrated that I.C.L operate technical change based on a marketing control mechanism. Whilst the function operated, it did not link with the other functions of anticipation and selection. The System Five in a viable system model of technical change describes such a framework.

(iii) From the summative evaluations the following conclusions are made: (a) the functions of the viable system model of technical change resulting from this research are an integral feature of technical change which can provide a reinterpretive account of the types of technical change which occur at I.C.L. (b) The structure provides a framework within which the viable process of technical change can take place by using these specified types of technical change. This can be extended to provide I.C.L with a particular typology for the types of technical change which can and do occur and present the necessary structured activities to create and prepare for a viable technical change process.

(iv) As a result of this evaluation I.C.L concluded that there was a major problem of information weakness between various business centre activities of technical change. This directly caused an increased time to present new technical product, designed and manufactured by I.C.L onto the market. The cause of this weakness was determined as a problem of transferring the implications of certain technical developments between the various business centres. The viable system model of technical change, therefore provides a viable framework which has the 'potential' to offer a new criteria for the successful introduction of new technologies and existing technical adaptations into the firm. This framework transcends the existing business centre boundaries, and provides the necessary functional aspects which can be interpreted by each business centre and transferred between them. This indicates an additional and necessary step towards a further reduction in I.C.L's 'time to market'.

These conclusions concerning the evaluation of the viable system model of technical change and the activities of I.C.L were presented to I.C.L's senior management in January 1990 and accepted. From this evaluation process, which has considered the activities of technical change in a practical context, the viable system model of technical change clearly does provide a comprehensive account of technical change in practice. It illustrates: (i) that the viable system model is acceptable as a scientific model and as a means for reinterpreting the new application area of technical change and (ii) that the function and structure of technical change can be effectively expressed through the viable system model.

This rigourous evaluation process presented in Chapters Six and Seven has considered the viable system model of technical change in both a theoretical and pragmatic domain. Chapter Eight describes the general conclusions derived from the three parts to this dissertation which concern: (i) the investigations into technical change, (ii) the development of a viable system model of technical change and (iii) evaluation of this model, which can be used to provide some lessons for the continued progression of Systems Science.

CHAPTER EIGHT

LESSONS FOR SYSTEMS SCIENCE

8.1 Introduction

In the opening Chapter of this thesis, it was argued that the increasing rate of technical change has created a rising frequency in the instability of the firm. This was attributed to the continuing application of outmoded ideas in coping with technical developments. It was from this particular scenario that it was identified that there was now a definite need to discover and adopt new ideas which could provide a controlling influence on the process of technical change.

The aim of this research has been to produce a system scientific model of technical change in order to provide an increased understanding of the problems associated with technical developments and to illustrate systemic viability in providing a realistic controlling framework on technical instabilities which might result from a process of technical change. The question this Chapter answers is, to what extent has the aim of this thesis been achieved?

Chapter Eight sets out to present the conclusions drawn from this particular systems research in three sections. These are: (i) to describe the main conclusions obtained in relation to the specific objectives outlined in Chapter One, (ii) to illustrate the contribution this research has made to the subjects of Systems Science and Technical Change and (iii) to outline the implications for continued systems research in the area of technical change.

8.2 Conclusions Drawn from the Research

A concise description of the objectives as detailed in Chapter One are as follows: (i) to analyse the current modelling approaches to technical change in order to identify the characteristics, the structures and the reasons for the emergence of technical change models. (ii) To identify a relevant link between existing modelling assumptions of technical change and a systems based modelling approach. (iii) To develop a system scientific model of technical change which illustrates the structural characteristics of technical change. (iv) To illustrate the unifying framework offered by the systems model through an evaluation of of existing theoretical assumptions of technical change. (v) To evaluate the use of the systems model in a practical application domain. (vi) To identify areas for continued systems research in technical change. In this section, the first five objectives are discussed in relation to the conclusions drawn from each Chapter, with a discussion concerning the final objective being presented in Section 8.4.

From the objective of analysing the current modelling approaches associated with technical change, the general question asked was, to what extent is there a structural coherence between the models of technical change? In general, it was considered that there was no one model which could currently being used to solve all the problems associated with technical change. This indicated that the structural coherence did not exist in the absolute sense.

Other conclusions indicated that: (i) a dramatic rise in technical change models in recent years had moved away from the dominance of the pre-1970 production function model to alternative analytical investigations which used particular structural assumptions regarding the nature of growth, competition, culture and in general, technical evolution. (ii) This increase in the diversity of the technical change models had taken place between the extreme assumptions of economic rationality and a behaviourist interpretation of technical change. Whilst this illustrated an expansion in the understanding and explanation of the various implications of technical change, it had taken place because there was a strong difference in the degree and manner of the structural assumptions. (iii) Whilst this diversity had developed, the tendency had also been to model the general characteristics associated with technical change. Despite their detailed structural differences, the aim of these models has been categorised in terms of a determined effort to monitor, measure or simply explain such characteristics. These characteristics were categorised into three categories: (a) technical uncertainty, (b) technical stability and (c) technical evolution. (iv) There has been no current consensus as to a general structure of technical change in the review of these models. This might only be achieved if there was a clear perception as to the nature of technical change. Establishing a coherent structure was an essential means in any possible future coordination of technical change models.

Existing model structures were identified by their reliance on particular associations. The conclusions from Chapter Three illustrated how such associations determined the particular structure of technical change models, and how they provided a possible basis for a coherent structure of technical change. It was found that structural analogies, used as a part of scientific inquiry, were concerned with the issue of matching two domains of knowledge by identifying structural commonalities through causal relations rather than in the elements themselves. This particular use of analogies provided a means for structural reinterpretation of the target domain of technical change, providing evidence for new facts, mediation, new theoretical insight, and also how the structures of technical change model were currently being determined.

Evolution analogies had provided a dominant structure for defining technical change models particularly in terms of growth, substitution and diffusion characteristics. Their continued use was found to illustrate an ignorance of its naturalistic limitations in terms of the characteristics of equilibrium and the assumption of natural qualities. The use of the production analogy gave an economic interpretation to a structure for technical change models. The dominant use of this analogy before the 1970's indicated that its general acceptability as a structure for technical change had significantly diminished over recent years. Whilst the analogy has provided a strong indication as to the mechanisms which produce technical changes, the assumptions of rationality, equilibrium, and an inability to explain characteristics derived from an evolution analogy, revealed the natural limitation of this analogy. By extending these analogies beyond their natural limits in order to explain such characteristics as uncertainty and instability suggested that their subsequent usefulness was doubtful.

The limitations in single analogical use had created a number of models which attempted to utilise a structure based on a multi-analogical context. These models had assumed that integrating the characteristics of more than one analogy could provide a more extensive structural description. The conclusion from this research was that the resulting structure only exhibited those characteristics which were common to both analogies, those being the common denominator characteristics.

These particular conclusions led to a relevant link between existing modelling assumptions and the use of a systems based modelling approach, which had been defined as the second objective of this research. Chapter Three illustrated that there was a need to determine a new comprehensive structural interpretation of technical change. The link was identified between these existing modelling assumptions of technical change and a system based modelling approach, by being defined through the use of a systems analogy. The analogy had to include the characteristics associated with stability, uncertainty and evolution, and in addition, present an appropriate form of systemacity, that is, an acceptable form of organisation which could utilise particular relations between these general characteristics. Establishing this systems analogy was essential to produce a new breed of technical change models, which could introduce new ideas and illustrate the necessary preparations for future technical changes.

Additionally, it was demonstrated how the appropriate system analogy could be used to create a new general structure which was to be used in technical change models.

Chapter Four discussed how such a system analogy could be incorporated into an approach which produced a system scientific model of technical change. It was shown that there was an inability to carry out any systems based investigation of a new structure without some form of preconceived model by which the analysis could be made. Without the precedence of any general model, the type of systems which could be used in the investigations of technical change could not be designed, they could only be managed.

Using the analogical meta-theory as presented by Counelis (1989), the location of the common core analogical region between both technical change and Systems Science was defined through the structural characteristics of both domains. The most appropriate system analogy was classified as the adaptive whole system. This particular system analogy contained statements regarding the structural relationships between three specific subsystems concerned with the activities of: (i) awareness, (ii) operations and (iii) monitoring and control. Similarities were shown to exist between these subsystems, and statements regarding the known activities of technical change which had been categorised into (i) evolution, (ii) stability and (iii) uncertainty activities.

Establishing these analogical ideas through the use of the adaptive whole system, a methodological approach to scientifically model technical change was developed. It was shown, using Beer's (1984) methodology of topological maps which consisted of a four stage process, that the analogical ideas developed in Counelis's (1989) meta-theory could be successfully adopted as a means to produce a structural model of technical change.

This led to the development a systems model which would reflect the necessary structural characteristics in the process of technical change. This being defined as the third research objective.

This four stage methodology topological maps produced a system scientific model of technical change based on the adaptive whole system analogy. The model presented a generalised systemic structure which indicated that: (i) the stability activities acts as a controlling mechanism reducing the effects of oscillatory activity within the adaptive whole system model of technical change. (ii) That the unpredictability of technical change, renders any form of accurate prediction of technical change meaningless. (iii) The isomorphism identified in the analysis did not present conclusive evidence that the generalised assumptions held in the adaptive whole system model accurately portrayed the systemic structure of technical change.

From this it was established that there were problems in defining the various functional characteristics of the monitoring and control subsystem. This led to an inability to help provide the appropriate structural characteristics of technical change. The link between the uncertainty and monitoring and control subsystems had not been defined in the adaptive whole system model of technical change. Whilst the analogical evidence suggested that the building blocks of the adaptive whole system were appropriate, it was considered that a more detailed example of the adaptive whole system analogy provided the basis for a second pass through the methodological approach in deriving a system scientific model of technical change.

This raised the issue of Beer's (1984) 'yo-yo' technique in the methodology. This technique illustrated a means of returning from the scientific model developed through the first four stages, and reassessing the value of the analogy in terms of insight gained from the methodological process. The 'yo-yo' technique created the necessary conditions for proceeding with another example from the same class of analogy.

The adaptive whole system model suggested that although the real sources of technical change are rooted within the existing system, the equilibrium hypothesis was incorrect for technical change. The consequence of this was that the adaptive whole system description of technical change illustrated situations of non-equilibrium, where the inner dynamics would produce new structures from their self-organisation (Jantsch, 1980). The indications were that a more detailed analogical investigation needed to be carried out to identify how self-organisation concepts within an adaptive whole system might be used to present a particular structure of technical change. One example within this class of analogy which illustrated self-organisation concepts and provided some positive system considerations to activities of control, adaptation and awareness, was identified as the viable system.

Chapter Five investigated how the viable system analogy illustrated a more detailed structural model of technical change, by using a second pass through Beer's (1984) methodology of topological maps. Similarities between technical change, the adaptive whole system and the viable system were defined through structural aspects associated with: (i) operations, (ii) controls and (iii) identification activities. The viable system analogy provided a more detailed description of the systemic structure of technical change. In particular the detailed structural relations operating between the operation, monitoring and control and awareness functions, revealed a process of technical change which could be described through a structure surrounding five specific systemic functions.

The link between the activities of a System One and technical change were identified by the generic changes which operated on the anatomical characteristics of technology and reflected through assumptions regarding technical adaptations. These were defined as: (i) technical product, (ii) technical process and (iii) technical knowledge activities. The change in each activity was structurally related to other activities which monitored and controlled the process of change. The structural necessity for System Two has been reflected by the assumed oscillatory implication of three System One's operating autonomously, whilst interacting with the other technical modes. There was necessarily a structural requirement to provide an anti-oscillatory mechanism. The analogical link was identified by the resemblance of oscillatory dynamics identified in the adaptive whole system model of technical change. A System Three of technical change has shown a structural explanation of how it is possible to coordinate, control and direct the adaptation activities in System One, directly. The implication of this structure, is that based on a total environmental consideration a System Three illustrated the necessary activities to select appropriate technical changes in relation to the overall system requirements of technical change.

The Systems One, Two and Three provided the detailed structure necessary to illustrate system activities associated with self-regulation. But rather than simply maintain a process of technical change, the emergent property in a systemic process of technical change had to be regarded in terms of technical progression and growth. This required self-organisational activities in an appropriate structural framework.

A System Four of technical change linked the activities required to forecast the necessary changes for technical progression and in doing so, reduce the effect of technical uncertainties. The ability to monitor the environment, and to transduce variety into the controlling function of System Three illustrated how the viable system of technical change could introduce self-organisational aspects. The link to a System Five in technical change was defined in terms of the final regulatory mechanism which conditioned technical changes to particular styles such as: (i) Fordist technology or (ii) post-Fordist technology. System Five described a function which regulated the residual variety between the interactions of Systems Three and Four.

Using these similarities between the five systems and technical change a conceptual model of a viable system of technical change was constructed. The viable system model of technical change described an illustration of how the necessary mechanisms required for the effective control in the technical change process had to be derived. It extended the adaptive whole system model of technical change by introducing the structural aspects of control specifically to technical change. This generated: (i) a model through which the firm could make preparations to reduce the possible damaging effects of technical change and, (ii) illustrated that particular types of control mechanisms were required to reduce the possibility of instability as identified in the adaptive whole system model, and through the simulation results of Chapter Four.

The viable system of technical change has provided a new and more detailed systemic structure of technical change in three particular ways: (i) as a particular example of the adaptive whole system, (ii) through the detailed structural descriptions of the five systems of the viable system, and their analogical link to technical change and (iii) through the creation of a conceptual model of a viable system of technical change which illustrated the necessary control mechanisms. This has provided the basis for identifying the structural framework for reducing the problems associated with the technical change as well as help to define the necessary functions required for a systems explanation of technical change.

The production of a conceptual description of the viable system model of technical change provided the ability to enhance and extend the viable system model as a unifying modelling framework for systemic investigation. This fourth research objective was achieved through a rigourous evaluation of existing descriptions and explanations of technical change, and identified and reflected certain similarities which exist between the different explanations of technical change. This was conducted using current economic and social theories in relation to the viable systems model.

The evaluation considered whether the viable system model of technical change was a comprehensive system scientific model for this subject. This was defined in terms of: (i) a needs, (ii) formative and (iii) a summative evaluation.

There was a particular need for the evaluation of the viable system model of technical change to both economic and human activity examples. This was defined in terms of the structural and functional framework in which a more coherent description and explanation of the particular activities of technical change would be achieved. This presented a framework which helped in: (i) the design and management of the financial activities which operate in relation to technical change, and (ii) the organisation and management of people in relation to technical change.

The five system functions and dependent relations of the viable system model provided a original basis for the reinterpretation of technical change. In particular these included: (i) the anatomical modes of technology which described the fundamental characteristics in technical change, and used to define particular changes in economic and human activity examples. (ii) The identification of instabilities in both examples was explained by the structural relations held between the anatomical modes and System Two, illustrating a structural mechanism which could be used to coordinate the damping of such instability. (iii) System Three was found to present the selection function of new technology in both economic and human activity examples. (iv) The anticipation function was identified with economic forecasts made to determine new technical developments. The indication was that a general framework for a social forecast of the implications of technical change was not currently evident. (v) The formative evaluation of System Five in both economic and human activity examples indicated that within the overall process of technical change there was a balancing mechanism which supported a particular style of technology. Whilst this was not evident in either theoretical example, it illustrated that this function and structural relation was a necessary feature which could be used to help explain the success or failure of technical changes.

From the summative evaluations it was shown that: (i) the viable system model provided a new and important framework through which a reinterpretation of particular types of technical change could be defined. (ii) It offered a means, for firms, by which the viability of technical change could be assessed. (iii) It created a structure by which a typology of technical changes could be generated, and help to provide an explanatory framework of the necessary functions of technical change.

The viable system model provided an appropriate mechanism which helped to describe and explain some of the present theoretical examples of technical change and also helps to create an extension to current theoretical descriptions of technical change by providing: (i) an acceptable structure, (ii) appropriate functions and (iii) an interdisciplinary systems model for technical change. The viable system model of technical change from this theoretical evaluation is clearly a comprehensive system scientific model.

In order to fully evaluate the viable system model of technical change, the question concerning how comprehensive a system scientific model has also been answered in relation to a practical evaluation. This linked the evaluation process of a comprehensive system scientific model of technical change to the fifth objective of this research which was to evaluate the systems model in terms of practical field research. This used field research data which had been gathered from a microelectronic based firm operating within a post-Fordist technical paradigm and affected by the problems associated with the process of technical change.

The conclusions from Chapter Seven indicated that the viable system model of technical change was shown to have demonstrated a comprehensive account of technical change in practice The three stages of the evaluation process conducted on the viable system model of technical change, to the practical examples identified at I.C.L, concluded that technical change in practice, offers two general characteristics: (i) opportunities which add value to the activity of the firm and (ii) problems which create poor performance in the firm. An explicit need, for I.C.L, was for an appropriate framework within which the opportunities offered by technical change could be exploited, and a framework which reduced the potential of poor performance initiated by the introduction of new technologies. The viable system model of technical change was considered to be a appropriate mechanism which offered two particular aspects: (i) specified functions and (ii) a structured framework for successful technical change.

The viable system model containing its five system functions and dependent relations provided a reinterpretation of the structural implications of technical change at I.C.L. In particular: (i) it provided a functional and structured framework of the practical system of technical adaptation operating within the two business centres of design and manufacturing. (ii) The dominant use of a control system structure in the operations of technical change at I.C.L, confirmed the importance of System Two activities. This was identified as a means to reduce instability, but that the current approach used could not effectively damp the instability currently affecting technical changes at I.C.L. (iii) System Three was described in the activities of technical change at I.C.L through a financial selection mechanism in the activities of design, manufacturing and strategy. (iv) The function of a System Four as an anticipatory mechanism was identified in the Future Systems Business Centre, particularly at the Advanced Information Systems Group. The structure provided an indication as to how the anticipation of new technology might be more effectively conducted. (v) A System Five illustrated that currently I.C.L operated with technical change being based on a marketing control mechanism. Whilst the control mechanism operated, it did not link with the other functions of anticipation and selection. The System Five in a viable system model of technical change offered the possibility of such a framework.

From the summative evaluations the following conclusions were made: (i) the functions of the viable system model are an integral feature of technical change which provides a systems based reinterpretive account of the types of technical change which occur at I.C.L. (ii) The structure provides a framework through which a viable process of technical change can take place. This could be extended to provide I.C.L with a particular typology for the types of technical change which could occur, and present the necessary structured activities to create and prepare for a viable technical change process.

As a result of this systemic evaluation I.C.L concluded that there was a major problem of information weakness between various business centre activities of technical change. This directly resulted in an increased time to launch any new technical product, which had been designed and manufactured by I.C.L, onto the market. The cause of this weakness was determined as a problem of transferring the implications of certain technical developments between the various business centres. The viable system model of technical change was shown to provide a framework which has the 'potential' to offer a new criteria for the introduction of new technologies and existing technical adaptations into the firm. This framework transcends existing business centre boundaries, and provides the necessary functional aspects which can be interpreted by each business centre and can be transferred between them. This indicated an additional and necessary step towards a further reduction in I.C.L's 'time to market'.

This evaluation process illustrated that: (i) that the viable system model is acceptable and useful as a means for reinterpreting the new application area of technical change and (ii) that the function and structure of technical change can be expressed through the viable system model in practice.

The contribution these conclusions have made to Systems Science and Technical Change in general are defined in the Section 8.3.

8.3 The Research Contribution to Systems Science and Technical Change

It is from these conclusions that the research contribution to Systems Science and Technical Change are made:

(i) The research contribution to the field of Systems Science has included:

(a) Identifying the applicability of the adaptive whole system and the viable system in an analogical context, and illustrating that the use of system analogies is a fundamental part of a system scientific method of inquiry.

(b) This research has shown that this use of the viable system model has extended its application well beyond the original domain of organisational structuring, helping to generate the necessary structures and functions of existing amorphous situations which may be designed in terms of viable systems.

(c) The conclusion is that the viable system can be used in an analogical context, and this has also been illustrated by the unique application of Stafford Beer's (1984) methodology of topological maps which has produced the system scientific model of technical change. This systems methodology has shown that it may be applied to different application domains other than those of organisations. The implication here is that this research has demonstrated the benefits of an alternative methodological approach, which can be extended to numerous application areas even beyond the use of the adaptive whole system and viable system analogies, to include other system analogies.

(d) The methodology has provided a comprehensive and new account of the viable systems of technical change. This has extended systems thinking into the subject of technical change, and has shown the benefits from such an approach. This indicates that future systems thinking can flourish in this analytically dominated subject.

(e) The practical evaluation has extended the proof that systems thinking 'in practice' is an effective means of reinterpreting existing situations. This research has also shown that the viable system model of technical change provides a means with which a new interpretation of technical change can be made in a practical context.

(ii) The research contribution to the field of technical change has included:

(a) a comprehensive analysis of technical change models which has provided new insight into the structures, functions and characteristics used. This analysis has produced a strong indication that the current approaches are limited by their continued use of assumptions regarding an equilibrium hypothesis, economic rationality or cognitive relations to technical characteristics.

(b) The viable system model of technical change provides an extension to existing approaches, by integrating existing characteristics within the new structure. This provides the necessary link between the achievements already established in technical change literature and the potential advances presented through this new structure of technical change defined through systems thinking.

(c) This systems research has provided a new direction for in the subject of technical change and in particular models of technical change. The framework provides an extension to both economic system and social system enquiries, but also introduces a general systems applications to this subject.

8.4 Implications for Continued Systems Research in Technical Change

The final objective of this research was to identify further areas for systems research in the subject area of technical change. The contributions which have been made to the subjects of Systems Science and technical change, have acted as a catalyst for a potential development programme of systems research in this subject. This specifically leads to a number of additional questions which need to be asked in order to create further advances in technical change using aspects of Systems Practice, Systems Technology and Systems Theory.

(i) Is it possible to develop the viable system model further? The continuing development of the viable systems model of technical change through the use of recursive embedments, and applied to various business firms, industrial sectors and particular types of technical changes. This will lead to a more detailed practical investigation of the structure associated with technical change and may also indicate a possible systems typology of technical change.

(ii) Is a workable tool necessary to support managers involved in the technical change process? This requires extensive field research to particular business sectors and firms to establish an informed insight as to the current assumptions of managers affected by technical change.

(iii) If it is necessary, is it possible to produce this support tool from the viable system model of technical change through the development of Systems Technology? The creation of this systems framework for technical change presents a structure can be used to develop possible support system architecture to help decision making in the complex and problematical process of technical change. The five system functions and their structural relation provide the basis for an integration of: (a) a technical characteristic database which would be developed by defined economic, engineering, social elements which define new technology. This would form the basis of a modal database of technical elements, which would be defined by a particular technical style. (b) This detailed database would be linked to selection procedures which might incorporate either: (i) Boolean or (ii) distribution selection criteria. The resulting selection would produce control, direction and coordination commands necessary to the process of technical change. (c) Additionally, the incorporation of a forecast model into the selection process would provide a more informed assessment of the necessary preparations for viable technical change and would be used in as a preparation rather than as a prediction mechanism. (d) A control system would be associated with the selection and anticipatory mechanisms, being driven by market conditions, technical characteristics or economic considerations. The potential of a workable support system for providing the necessary information for effective and viable technical change would be developed from the viable system model of technical change identified in this research. These four aspects would form the basis of an integrated systems research programme which would have to utilise the information obtained in field research on the effects of technical change on the firm in relation to the viable system model.

(iv) Can Systems Theory be extended to provide new insight on the nature of technical change? The use of the viable system model of technical change has illustrated a systems based reinterpretive account to existing modelling approaches. The viable system is founded on systems and cybernetic theory, and therefore, the viable system model can be used as a basis for extending existing system theoretic descriptions of technical change which could include a comprehensive systems explanation of how technical change occurs, the reasons why such changes take place, and a theoretical explanation of the effects of these changes.

This research has produced a system scientific model of technical change which provides an increased understanding of the problems associated with technical developments. It has also demonstrated a clear ability to provide an important form of controlling framework for technical instabilities which results from a process of technical change.

In summary, it has been argued in this systems research that the subject of technical change has, rather surprisingly, continued to use outmoded ideas to explain the the causes and effects of technical change. This has created the need to develop a framework for introducing new ideas to the subject. Using Beer's (1984) methodology of topological maps, and incorporating the adaptive whole system and viable system in an analogical context, this unique approach has produced a reinterpretive account of the structure and functions of technical change. The viable system model of technical change is complementarity to the basic characteristics of theoretical and practical examples, but provides a new direction which extends these characteristics into a new structural and functional framework of technical change. This orientation has provided a basis for contributing new ideas and a new model to the subject of technical change and effectively demonstrated the use of the viable system model in a new application areas, extended the use of analogy in system scientific thinking and further shown the importance and significance of systems thinking in practice. It has also created a basis for a continuing programme of systems research in the subject of technical change.

APPENDIX I

BACKGROUND NOTES ON THE ACTIVITIES OF I.C.L, KIDSGROVE

A1.1 An Introduction to I.C.L

International Computers Limited, I.C.L, is a leading computer manufacturer, formed in 1968 from a merger between English Electric Computers and ICT. I.C.L in 1984, itself merged with the Standard Telephone and Cables Group, becoming a major operating subsidiary with the principal business focus on communication and information system technologies. I.C.L functions around a number of business centres, each being associated with a particular market sector, for example, in defence, office systems or retail. These are supported by a number of services, such as manufacturing operations, marketing, technical support, consultancy services which operate through the business centre philosophy.

A1.2 The Activities of I.C.L, Kidsgrove

Four principal activities highlight the key role of I.C.L, Kidsgrove, within the overall I.C.L operation. They consist of manufacturing in terms of: (i) assembly and test, (ii) design, (iii) bare board processing, and (iv) component operations.

The manufacturing facility at Kidsgrove functions so as to: (i) assemble and test technical components, (ii) process multi-layer bare boards, and printed circuit boards and (iii) construct a number of I.C.L machines, built solely on site.

The design and engineering services are used to provide development support services as well as design tasks in order to provide technical computer aided manufacture and test support to the manufacturing operations. Its aim is to provide design information for: (i) printed circuit board layout, (ii) artworks and (iii) mechanical assemblies. Other aspects include: (i) new testing techniques, (ii) prototype construction as well as (iii) transferring design information to manufacture.

Bare board processing combines complex operations of electro-chemical processes in addition to electronic and mechanical activities. This involves: (i) the creation of the design artwork onto film through a computer aided design of the circuit pattern. (ii) Generating voltage layers on the bare board which is laminated with light sensitive film so that a photo print image of the artwork can be put onto the board. (iii) Creating buried logic layers using electro-plating and multi-head numerically controlled computers. (iv) Creating the final bonded board by baking the board, additional electrolysis and the use of other chemicals to remove unwanted metals on the board. As a result the manufacture of printed circuit boards is at the heart of bare board processing.

An additional function at I.C.L, Kidsgrove is to comprehensively test all equipment and incoming components in terms of the I.C.L design specification. Effective storage and handling of these components is achieved at Kidsgrove, providing an essential link in the manufacturing chain. Testing is carried out on: (i) all new technical components suitable for an I.C.L kit, through reliability assessments defining component quality, applying power and heat, automated testing, and individual testing. (ii) Testing at the stages of automatic insertion, robot assembly and surface mounting is carried out three times during the complete process. (iii) After the PCB has been cleaned additional tests include: (a) inspection of solder joints, (b) complete sample inspection, (c) automatic testing of boards for basic assembly faults, (d) automatic test of individual components, (e) a functional test for correct overall outputs, (f) an after test assembly inspection for connectors and metal fixings and (g) a final inspection.

In general the manufacture of PCB's follows the route specified in figure A1.1.

To create the competitive edge to other PCB manufacturers, I.C.L, Kidsgrove attempt to provide: (i) customer service and flexibility to customer demand, (ii) a short time to market, (iii) cost reductions and (iv) continual improvement in quality products and services.

It is from this need to create the competitive edge in a short time to market in manufacturing where this particular systems research started.

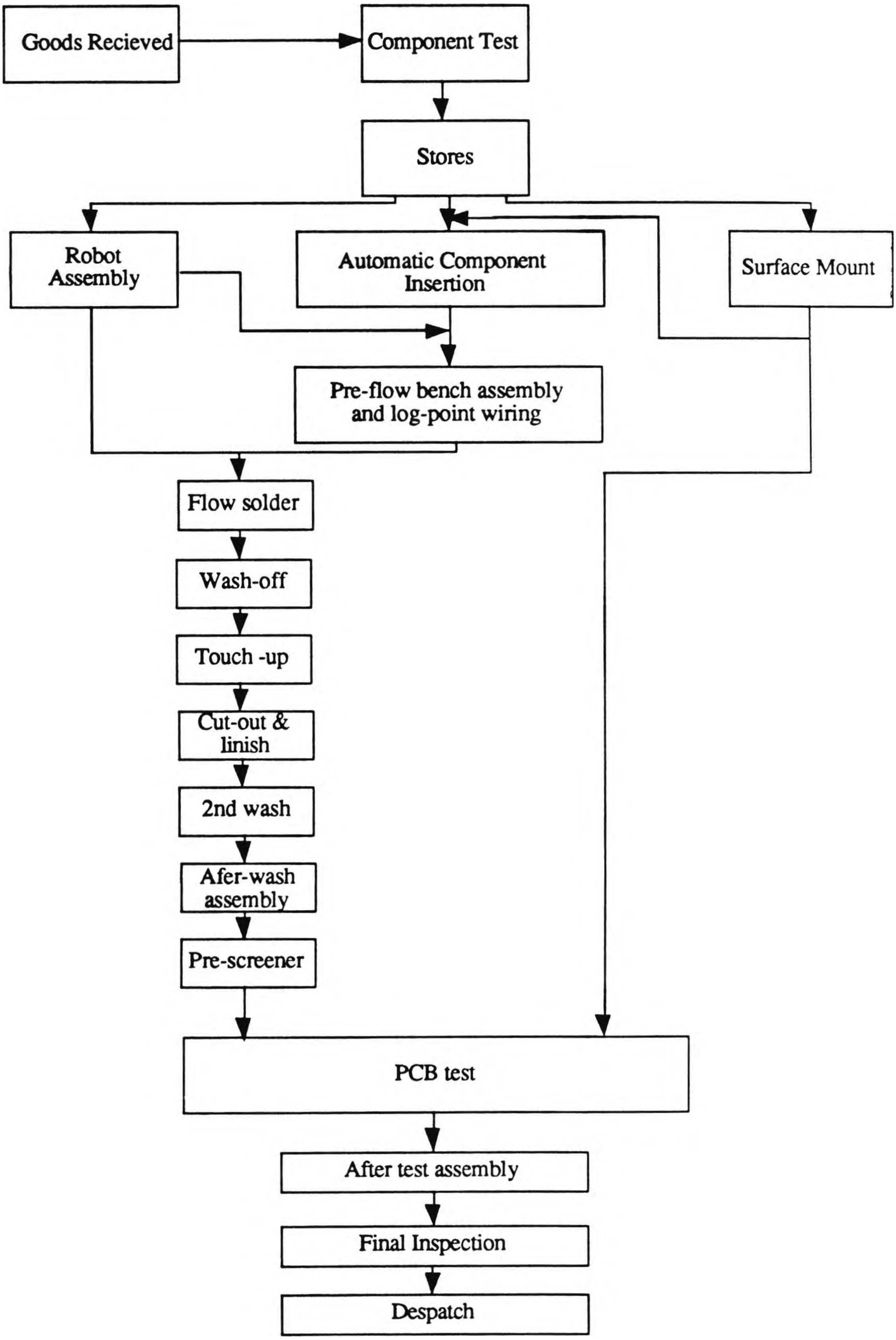


Figure A1.1 the manufacturing and testing process of PCB's

A1.3 A Timetable of Systems Research at I.C.L

The sequence of stages in this fieldwork included: (i) an orientation of the inquiry, (ii) an opening of inquiry, (iii) systematisation of inquiry (iv) follow up and (v) cross checking (Ellen, 1987). Using these five stages four visits to I.C.L, Kidsgrove were timetabled:

(i) 6th March 1989. An initial meeting of academics and senior management of I.C.L was set up to analyse the the effect new information technology could have on the reduction of 'time to market' in manufacturing. An account of this meeting was discussed in the internal newspaper, the "ICL Gazette' and is illustrated in figure A1.2. this helped to indicate a provisional map of the boundaries of this systems research with the activities of I.C.L expressed at the meeting.

(ii) 28th April 1989. An introduction to some of the background data of the operations at I.C.L was determined. These statistics included: (a) I.C.L produce over 7500 different product items, ranging in price from £0.8k to £3.0k. (b) I.C.L rely on collaborative work on the assumption that this strategy brings newer and more efficient technologies into their products. (c) Existing product life cycles are approximately two years. The last four years has seen a reduction in the time to market from: 1985=40 days, 1986= 21 days, 1987=13 days and 1988=10 days. (d) There was an existing 8% discard rate of manufactured PCB's. (e) Staff enjoyed job-rotation. (f) Testing took place on 50% of current manufacturing operations. From this information a discussion on a particular foundation for the systems research resulted in an analysis of current operations in regard to the impact of future technical changes on product and process technology developments. This led to a systematisation of the inquiry in relation to the research, and was to be continued at a later stage.

(iii) 17th-21st July 1989. A five day visit to I.C.L, Kidsgrove included interviews with key personnel in the business centres of manufacturing, design, future systems and strategy. Potential interviewees were obtained as to their organisational position in relation to technical change, and from those, interviews were carried out with the selected personnel who were particularly willing to express their view of technical change in relation to I.C.L, Kidsgrove. The data collected from these interviews were classified into the impact of technical change in these four areas. A report was subsequently given to the Business Liaison Manager at I.C.L to generate the necessary feedback and to establish whether the date collected had been interpreted correctly.

TECHNOLOGY

FOCUS IS ON MANUFACTURING

TWENTY top international academics were joined by ICL manufacturing experts recently to look at issues facing manufacturing industry.

In particular, they result from constantly reducing the time to put new products on the market.

The manufacturing workshop, held at Wokefield Park, Reading (REA 14) in March, is one of several sponsored by ICL's University Research Council.

With the theme of applying information technology, the workshops' main objective is to bring senior ICL staff closer to current academic research, and to explore future research and collaboration.

Academic delegates from the UK were accompanied at the workshop — titled 'Time to Market' — by professors from the USA, Germany, France, Holland and Finland.

They were welcomed by John Dickson, chief operating executive and managing director of ICL Product Operations.

He outlined the dramatic improvements ICL has made in on-time deliveries, inventory reductions, productivity and quality and reliability.

He said, 'The challenge now is to to reduce the time from conceptual design to production'.

ICL has set itself the target of a 50 per cent reduction to focus the company's efforts. And John Dickson added, 'No product would be exempt from this goal'.

Keynote speaker at the event was Prof. Steven Wheelwright, professor of business administration at Harvard Business School.

He said his research, particularly in the automotive industry, included comparisons between Japanese, American and European manufacturers.

Prof. Wheelwright said, 'Japanese designers place strong emphasis on testing their view of the world with that of the end user.

'Honda design engineers, for example, spend two months a year talking to customers and more time travelling than any other staff group in the company.'

And their designers do not keep to the conventional wisdom of using commonplace components to make design and manufacturing easier. Some 62 per cent of automotive components are what Prof. Wheelwright calls 'black box parts'.

These are essentially parts uniquely specified to the car company and then handed over to a supplier to use its special skill to design and make.

Study time: Academic and ICL experts concentrated on crucial issues facing manufacturing industry at a top level ICL University Research Council workshop.

In the US and Europe, car companies tend to design the parts themselves and use the suppliers to make them.

Prof. Wheelwright's research also revealed that in firms like Honda and Toyota, information transfer between design and engineering was a continuous, rather than batch process.

Manufacturing engineers also became involved in the process at the beginning of the design phase — encouraging an early commitment to full-scale production.

The result is that the Japanese need half as many engineering hours for a new model as the US, and less than half of that of European car makers.

The success of these philosophies is reflected in the ability of the Japanese car makers to launch a new vehicle within 18-24 months and make complex engine modifications in eight months.

Unlike US and European car makers, who shut down their lines for weeks, Honda performs running model changeovers during the weekend. The workshop ended with academic and ICL delegates forming syndicates in a number of key areas to discuss and identify management actions, and opportunities for information techology and future research.

These results will be published in a special edition of the ICL technical journal.

Figure A1.2 the focus is on manufacturing- 6th March 1989 (ICL Gazette, 1989, p. 4)

Although Manufacturing Operations has three main production sites at Kidsgrove, Letchworth and Ashton, the information was obtained solely at the Kidsgrove plant, and provide the basis for the practical evaluation of the viable system model of technical change, as developed in Chapter Five.

(iv) 10th January 1990. Having reflected upon the results of this qualitative analysis, the conclusions obtained from the evaluation of the viable system model of technical change in relation to the current practices of technical change were presented to the senior management of I.C.L Manufacturing Operations at Kidsgrove. The conclusions reached in this thesis were accepted and provided a basis for future research with I.C.L in terms of using information technology to support the process of technical change.

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