A Fitness Landscape Model For Manufacturing Strategy

Yong Kiang Tan

May 2001

A thesis submitted for the degree of Doctor of Philosophy

Department of Mechanical Engineering

The University of Sheffield

Abstract

Many studies analyse manufacturing organisations and their problems by reducing or simply throwing away the interacting components, with the assumption that the latter are either negligible or behave linearly. These studies (referred to as reductionism) tend to overlook the importance of these interacting components. An alternative view is to adopt a "complex systems" approach, to understand the manufacturing organisation as a system which evolves over time by adopting characteristics to survive. The aim of this research was to study the development and application of fitness landscape theory (a theory that is part of complex systems theory) in understanding and formulating manufacturing strategy. The creation and application of fitness landscape models to help search and select capabilities for manufacturing strategy is the principal area of novelty within this thesis.

Several researchers (Maguire, 1997b; Merry, 1998; Beinhocker, 1999) had noted that fitness landscape theory was an appropriate theory for investigating and understanding strategy, but none of these papers made any attempt to understand fitness and relate it to organisations in terms of competitiveness, effectiveness or survival. With this gap and above introduction the contribution that this thesis makes to knowledge is in the following areas:

- The creation of knowledge on the boundaries and detail of complex systems theory. This is summarised by a framework that relates the various concepts to manufacturing management issues.
- To study manufacturing strategy. This thesis treats manufacturing organisations as complex adaptive systems, with goal directed behaviour.
- The creation of a definition and model of "fitness" that is appropriate for organisations in general. This is then developed into a manufacturing specific definition and model. It was concluded that to increase fitness, a manufacturing organisation must possess the ability to inherit, imitate and search manufacturing strategy (or configuration) such as quality, delivery, flexibility, and cost.

- The above definitions and models are then related to manufacturing strategy formulation in terms of the acquisition of specific capabilities (cost, quality, flexibility and delivery)
- The models are then applied and tested on a population of UK manufacturing organisations to explore the relationship between fitness and capabilities. A map which indicates the relative fitness contribution by the four manufacturing capabilities is presented.

Acknowledgements

I would like to express my sincere gratitude to my supervisor, Dr Ian P. McCarthy for his continual help, encouragement, valuable guidance and advice throughout this entire duration of this research. Despite his career move to University of Warwick one and a half years ago, Dr McCarthy devoted the same effort and enthusiasm in supervising me in this research.

The assistance given by all the colleagues, Christos Tsinopoulos, Pavel Fernandez, Dr Thierry Rakotobe-Joel, during these three years is highly appreciated.

I would like to extend my gratitude to Warwick Manufacturing Group, University of Warwick for approving the use of data gathered from Manufacturing Excellence Award 2000 competition. Without which, this study would not be completed so swiftly.

Finally, but no mean least, I would like to thank my lovely wife, Lee Ming who constantly encourages and loves me.

Publications

The publications that have been made as a result of this research are:

Tan, Y. K. and McCarthy, I. P. 'Manufacturing Competitiveness And Fitness Landscape Theory', 15th International Conference on Computer Aided Production Engineering (CAPE 1999), Maropoulos, P.G., McGeough, J.A., (Eds), University of Durham, April 1999.

McCarthy, I. P. and Tan, Y. K. (2000). 'Manufacturing Competitiveness And Fitness Landscape Theory'. *Journal of Materials Processing Technology* - Special Issue on Agile/Responsive Manufacturing on a Global Basis, Vol.107 : 1-3, pg. 347-352.

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

1.1 Background Of The Research

UK manufacturing has had a mixed history and recently many people have argued that it is in terminal decline and has no future in the UK. Others have suggested that in the future, only minor volumes of physical production activity will take place in the UK and that the UK will concentrate on activities such as design, research and marketing. Yes, the face and body of today's manufacturing is changing, but this has been always been the case, especially over the last 50 years, with UK and world manufacturing reducing waste and enhancing quality, whilst becoming more effective. Also, over the last 20 years manufacturing has strategically outsourced support operations such as logistics, finance, IT and catering so as to focus on core business processes, such as research, design, process and technology development and production. The obvious outcome over this period, is that UK manufacturing, along with the manufacturing sectors of other leading nations has become more streamlined and competitive.

The share of Gross Domestic Product (GDP) for UK manufacturing decreased from 30 per cent in 1970 to 22 per cent in 1997, nevertheless, it still plays as an important role in the UK economy. Kitson and Michie (1996) noted that from the period between 1973 and 1992, the total increase in UK manufactured output was only 1.3%, whereas the other leading nations had significantly higher output, for example Japan 68.9%, Italy 68.6%, USA 55.2%, West Germany 32.1% and France 16.5% for the same period. Kitson and Michie suggested that this poor industry performance has stagnated the growth of the whole UK economy.

In 1994, to help realise the importance of UK manufacturing, the UK government introduced a White Paper on "*Competitiveness*". The objective of this Paper was to increase productivity growth and trade performance for UK industry. In 1997, a report from the CBI's National Manufacturing Council "*Fit for the Future*" (Confederation of British Industry, 1997) claimed that an additional £60 billion a year could be added to UK GDP if manufacturing performance could be raised to the USA levels. Such an increase would represent around 8% of 1997 GDP of £756 billion. UK manufacturing could become fitter after programs of cost-cutting and efficiency gain. There are a number of key areas, including communicating with the workforce, over-stocking, lead time issues, service and quality, where competitiveness must be improved. With such room for improvement, it came as no surprise when the net rate of return for UK manufacturing companies rose to 11% in 1998. However, the main question of this thesis is what does the term "*fit*" mean in the literature stated above, and how does this relate to the concept of "*fitness*" as discussed in a complex systems theory context in Chapter 4.

Research by the Alex Lawrie Factors in 1999 on 300 small and medium-sized enterprises with a turnover of less than £1 million found that ninety per cent of manufacturing companies see making a profit as their number one priority when starting up a business (Alex Lawrie Factors, 1999). This also relates to the ideas presented by Goldratt and Cox (1993) in their book "The Goal", where the goal of any organisation is to make money. Without profit, a company will not be in business for long. Hence, on the face of it being *fit* would appear to simply mean that a company must be able to compete successfully and make a profit in a national or international competitive environment, not only for now, but also equally important, in the future. In other words, it is equally important for the company to survive in the short term as well as the long term.

This background, raises some significant questions: What factors contribute to the "fitness" of a manufacturing company? What are the signs that one company is fitter than another? What should companies do to stay fit? The main question for the management of manufacturing companies is what should be implemented to increase this fitness without "tearing" down the whole company structure and rebuilding it from scratch. It is no secret that changes especially in strategy require resources such as time and money, so it would be catastrophic for management to just adopt a "trial and error" approach to see which new strategy suits their business needs. It would be valuable for organisations to have a model which informs them of the benefits of implementing different manufacturing strategies.

1.1.1 Manufacturing Needs

In today's competitive commercial climate, manufacturing organisations need to improve their manufacturing performance in order to stay in business. To achieve this, there is a need for manufacturing managers to focus on the formation of appropriate manufacturing strategies. However, formulating manufacturing strategy is a difficult and multi-dimensional process. Although there is vast literature on this topic and the role of manufacturing capabilities, there are still different opinions on whether multiple manufacturing capabilities complement or inhibit one another. This problem is summed up by the two contradictory models - *trade-off* and *cumulative* as proposed by two distinct camps of scholars (This is discussed in Chapter 6). With this issue, this thesis will investigate how the manufacturing capabilities correlate to one and how managers should formulate manufacturing strategies using a *complex systems theory* perspective.

Although manufacturing strategy as a research area is "well trodden", it is a diverse and constant subject. This thesis explores how manufacturing competitiveness, strategy and fitness relate to each other. To achieve this, the research adopts a complex systems approach to defining, understanding and modelling manufacturing fitness, i.e. *fitness landscape theory*.

Fitness landscape theory is a concept that was developed by the biological sciences, but has become well-known in areas such as economics, organisational studies, and computer science. The novelty of this thesis is that it attempts to develop and translate this approach into a manufacturing context. Thus, the primary aim of this research is to produce a model which could be used to assist manufacturing companies in navigating the competitiveness (fitness) landscape that is available through different manufacturing strategies. The model could be used as tool for management to understand the advantages of combining different aspects of manufacturing strategy. By using this model, management could judge the benefit or fitness increase and the options that are available with each strategy.

1.2 Aim and Objectives

This thesis is concerned with the development and application of fitness landscape theory for the purposes of formulating manufacturing strategies. The thesis introduces fitness landscape theory and concepts from *complex systems theory* that have emerged in the last two decades. The thesis then provides a detailed review of fitness landscape theory in order to understand how it could be both developed and applied to the area of manufacturing strategy.

To set the scene for the model, a review of literature on manufacturing strategy, competitiveness and performance indicators for manufacturing companies is presented. A model of manufacturing fitness is then proposed. This model includes a definition and function of what constitutes manufacturing fitness in terms of manufacturing strategy. To provide validation and further understanding, this model is then tested by producing a fitness landscape for a population of manufacturing organisation based on a survey of the Manufacturing Excellence 2000 (MX2000) participants.

In summary, the research questions that this thesis addresses are:

1) What is complex systems theory and what is its relevance to manufacturing?
2) From a complex systems perspective, what is fitness in a manufacturing context?
3) What are the implementations and applications of fitness landscape theory?
4) How can the concept of manufacturing fitness be modelled and applied?

1.3 Research Methodology

Graziano and Raulin (1989) observed that scientific research usually proceeds in an orderly manner, from one phase to another. They suggested that these phases of research could be classified from initial ideas to problem definitions, to procedures design, to empirical observations, to data processing, interpretation, and communication. Each phase is distinctive to the other and different tasks are undertaken to prepare the work for the next phase. Figure 1.1 shows the interpretation of the research process. This model was used as a guide for conducting this research.

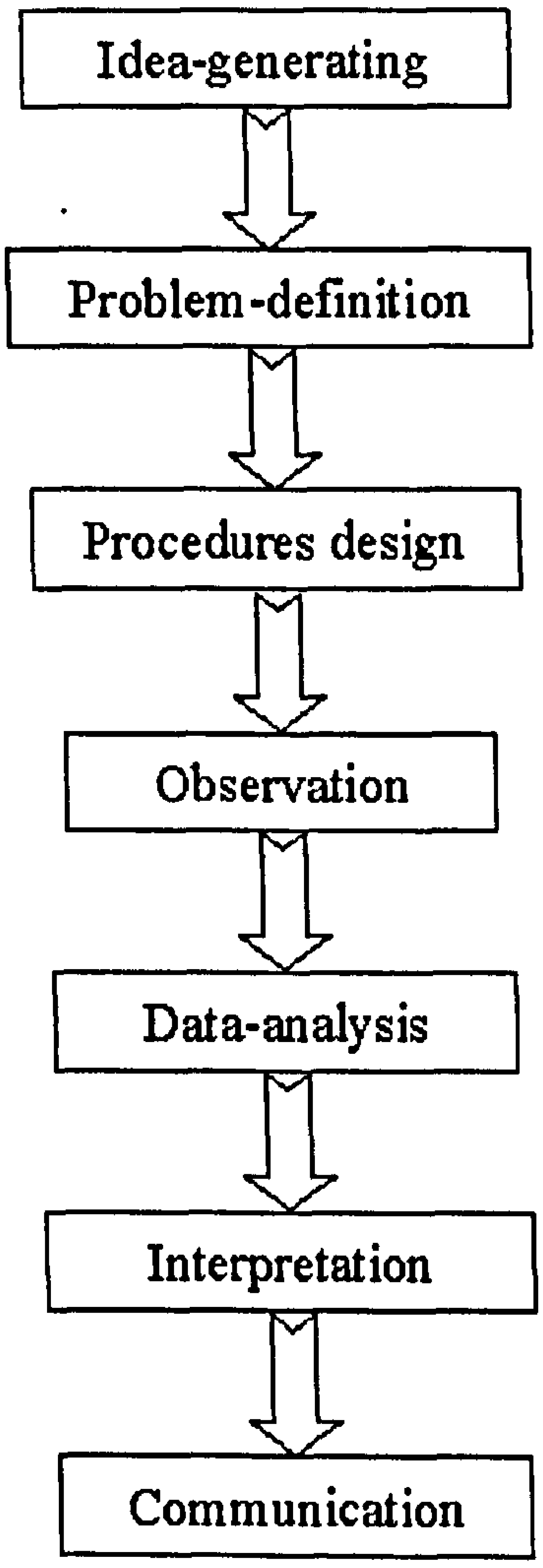


Figure 1.1 Research Process

Idea-generating phase. All research begins with an idea, sometimes quite vague. The researcher's interest in the idea is important.

Problem-definition phase. Vague ideas are not sufficient to conduct a scientific research. Therefore more work is needed to clarify and refine these vague ideas. In this phase, the initial ideas are systematically developed and refined. This involves a thorough search and understanding of the relevant literature.

Procedures-design phase. In this phase, the researcher systematically determines what observations are to be made and exactly how they are to be made.

Observation phase. In this phase, the procedures determined in the previous phase are performed. The observation phase is central in all science. Empirical observations make up the facts of research. When the researcher records the observed facts, that record constitutes the research data.

Data-analysis phase. In most research studies, the data will be in the form of a numerical record representing the observations, and the numerical data must be put into some order and further processed. Statistical procedures are often used to describe and evaluate numerical data. The nature of the research questions and the observational procedures determine which statistical procedures are to be used in this phase.

Interpretation phase. Having statistically analysed the data, the results are interpreted in terms of: (1) how they help to answer the research questions, and (2) how this answer contributes to current knowledge in the field. These answers are compared with the theoretical predictions and constructs.

Communication phase. Science is a public enterprise, and one of its most basic components is communication among scientists. This communication occurs through oral presentations at scientific meetings and written accounts in journals and books.

1.4 Outline of Thesis

Chapter 1 provides an introduction to the thesis. It provides an overview to the problems that manufacturing is facing and introduces in detail, the research aims and objectives. This chapter also outlines the approach used for conducting this research. Figure 1.2 concludes this chapter by showing the overview of the thesis structure.

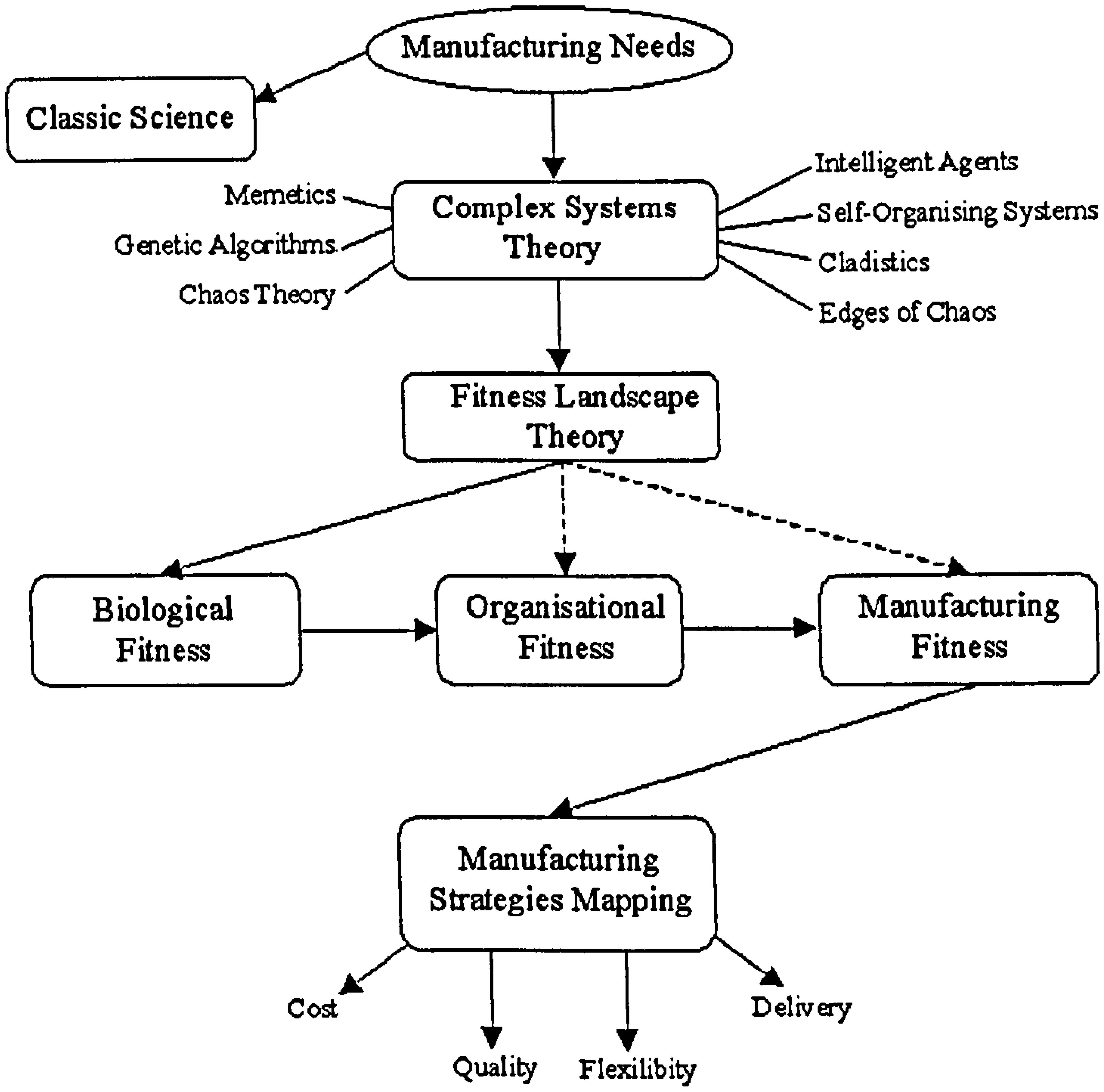


Figure 1.2 Overview of Thesis Structure

Chapter 2 introduces the research methodology that guides this study. It gives the outline of the various research activities in each stage of the research. Furthermore, it provides forethought on the selection and usage of the data collection method.

Chapter 3 introduces the concept of complex adaptive systems (CAS) from complex systems theory. This chapter also discusses the various metaphors, tools and techniques in complex systems theory and where appropriate relates them to a manufacturing context.

Chapter 4 describes in detail fitness landscape theory which is one of the tools in complex systems theory. Taking a cross disciplinary approach this chapter relates fitness landscape theory to the study of organisations and manufacturing organisations in particular.

Chapter 5 investigates in detail the concept of fitness in biological and organisational studies in order to develop and apply fitness landscape theory to manufacturing organisations. By exploring these metaphors and models of biological and organisational fitness, a definition of manufacturing fitness is proposed.

Chapter 6 takes the definition proposed in Chapter 5 and develops this into a conceptual model of manufacturing fitness. This model is based on four capabilities of manufacturing strategy: quality, delivery, flexibility and cost. Each individual capability is studied in depth and described according to its various attributes. Finally, a fitness landscape model is proposed .

Chapter 7 presents the methodology for identifying and estimating the fitness of manufacturing organisations based on the attributes described in Chapter 5 and Chapter 6. Based on these data, this chapter also presents the fitness path for manufacturing organisations.

Chapter 8 concludes the findings and novelty of this research. It details the limitations of this study and proposes an agenda for future research in this area.

Chapter 2. Research Methodology and Design

2.1 Introduction

To help enhance the quality of the research process and outputs a recognised methodology should be used. Hussey and Hussey (1997) defined *methodology* as the overall approach to the research process, including the theoretical underpinning to the collection and analysis of the data. They further distinguished *method* from methodology as the means by which data can be collected and/or analysis.

This chapter explains the methodology used in this research. The first section introduces the different classifications of research and provides an overview of how research is categorised. The second section discusses the research process, particular in terms of research design and survey methods. The third section relates sections two and three to the research presented in this thesis. This revolves around five stages: *needs analysis*, *review of relevant concepts*, *formulate fitness model*, *application of model*, and *review and conclusion*. The fourth section deals with data collection and the secondary data method used in this research. This section begins by explaining the concept of secondary data and then describes the variables and performances data taken from the Manufacturing Excellence 2000 competition (Mx2000) for this thesis.

2.2 Types of Research

Sekaran (2000, pg. 2) defined research as the process of finding solutions to a problem after a thorough study and analysis of the situation factors. From this statement, there are four possible aims of research:

- to gain familiarity with a phenomenon or to gain insight,
- to describe things,
- to determine associations between variables, and/or
- to test hypotheses.

Since research design is closely linked to a researcher's objectives, there are several types or approaches to research. The following section introduces some of the most common types.

2.2.1 Applied versus Basic Research

A common aspiration of research is to solve real problems that lead to benefits for industry, society, government or other stake holders. For example, a particular type of production line configuration may not be performing well and a company would like to investigate the reasons for this, in order to take corrective action. Such research is called *applied research* as the output and research environment is pragmatic. The theory, methods and ideas that are used to examine the problem are usually the basis of the novelty.

If the research has no application in the short or medium term, but instead aims to generate a body of knowledge about how certain problems occur in organisations, then this type of research is called *basic research*. For example, a team of scientists might be looking to develop new simulation techniques using super computer technology. The aim of the research is to develop new processing algorithms for the simulation using case study data collected from a manufacturing company. Thus the research is not directly concerned with helping the manufacturing company, but rather in developing knowledge on algorithms. In short, the findings from basic research can be applied in other fields at another time, whilst the findings from applied research are put to use in the organisation now.

Thus, research done with the intention of applying the results to solve specific problems is applied research, while research which is chiefly to enhance the understanding of certain academic disciplines is called basic research (or fundamental research/pure research). Table 2.1 summarises the differences between the two research types.

Basic research ⟷	Applied research
Purpose: • Expand knowledge of processes of business and management • Results in universal principles relating to the process and its relationship to outcomes • Findings of significance and value to society in general	Purpose: • Improve understanding of particular business or management problem • Results in solution to problem • New knowledge limited to problem • Findings of practical relevance and value to manager(s) in organisation(s)
Context: • Undertaken by people based in universities • Choice of topic and objectives determined by the researcher • Flexible time-scales	Context: • Undertaken by people based in a variety of settings including organisations and universities • Objectives negotiated with originator • Tight time-scales

Source: Saunders et al. (2000), pg. 3

Table 2.1 Basic and Applied Research

2.2.2 Empirical versus Theoretical Research

Empirical research is based on *the results of observation*, whilst theoretical research is concerned with *the theory of a subject*. Theoretical research begins by developing a theory of using a priori knowledge, the theory is then tested using a variety of methods including data collection and case studies. Empirical research gathers the data (empirical evidence) and then processes this evidence using numerical tools. The observations identified and the resulting theory are formed primarily from this statistical process. Hence, the data employed is used to construct the empirical research, instead of supporting the research, as is the case with theoretical approach.

Although it is obvious that these two approaches are entirely different, they are both regarded as valuable ways of building knowledge. However, it is not always easy to distinguish them apart, as most research projects involve both theoretical and empirical approaches. Before any empirical investigation can be conducted, the researcher has to have some understanding of the entity/subject under investigation and therefore holds some form of theoretical position. Without studying the subject, the empiricist is not able to properly understand the problems and hence is limited in the collection of empirical evidence. Likewise the theorist, without the evidence presented by existing studies, is unlikely to have ideas or arguments to build on.

Theoretical research, therefore, does not occur in a vacuum. It is the result of rationalising the findings of previous empirical studies and presenting different views from the interpretations previously made.

2.2.3 Positivistic versus Phenomenological Research

Positivistic research is based on the statistical analysis of data collected by means of descriptive and comparative studies and experiments. It assumes that only knowledge obtained by means of measurement and objective identification can be considered to be valid. Also, this method presupposes that the researcher is detached from the subject of research and thus cannot influence it or be influenced by it. The main principle of analysis is the cause and effect of the variables under study.

The *phenomenological* approach uses a more personal and interpretative process in order to "understand reality". Reality is interpreted by the researcher who observes and experiences the situation. Without this interacting role between the researcher and the situation, rich insights into the complex research areas are often lost. Therefore by interpreting and understanding a problem from different viewpoints, an enhanced understanding is achieved. In other words, by translating the realities and having empathy with reality allows knowledge to be accumulated.

Some major differences between these two research approaches are presented in Table 2.2.

Positivistic Research	*Phenomenological Research*
• Research concentrates on description and explanation.	• Research concentrates on understanding and interpretation.
• Well-defined, narrow studies	• Narrow as well as total studies (holistic view)
• Research concentrates on generalisation and abstraction.	• Researchers concentrate on the specific and concrete ("local theory") but also attempt generalisations.
• Statistical and mathematical techniques for quantitative processing of data are central.	• Data are primarily non-quantitative.
• Researchers are detached, i.e., they maintain a distance between themselves and the objective of research; take on the role of external observer.	• Both distance and commitment; researchers are actors who also want to experience what they are studying from the inside.

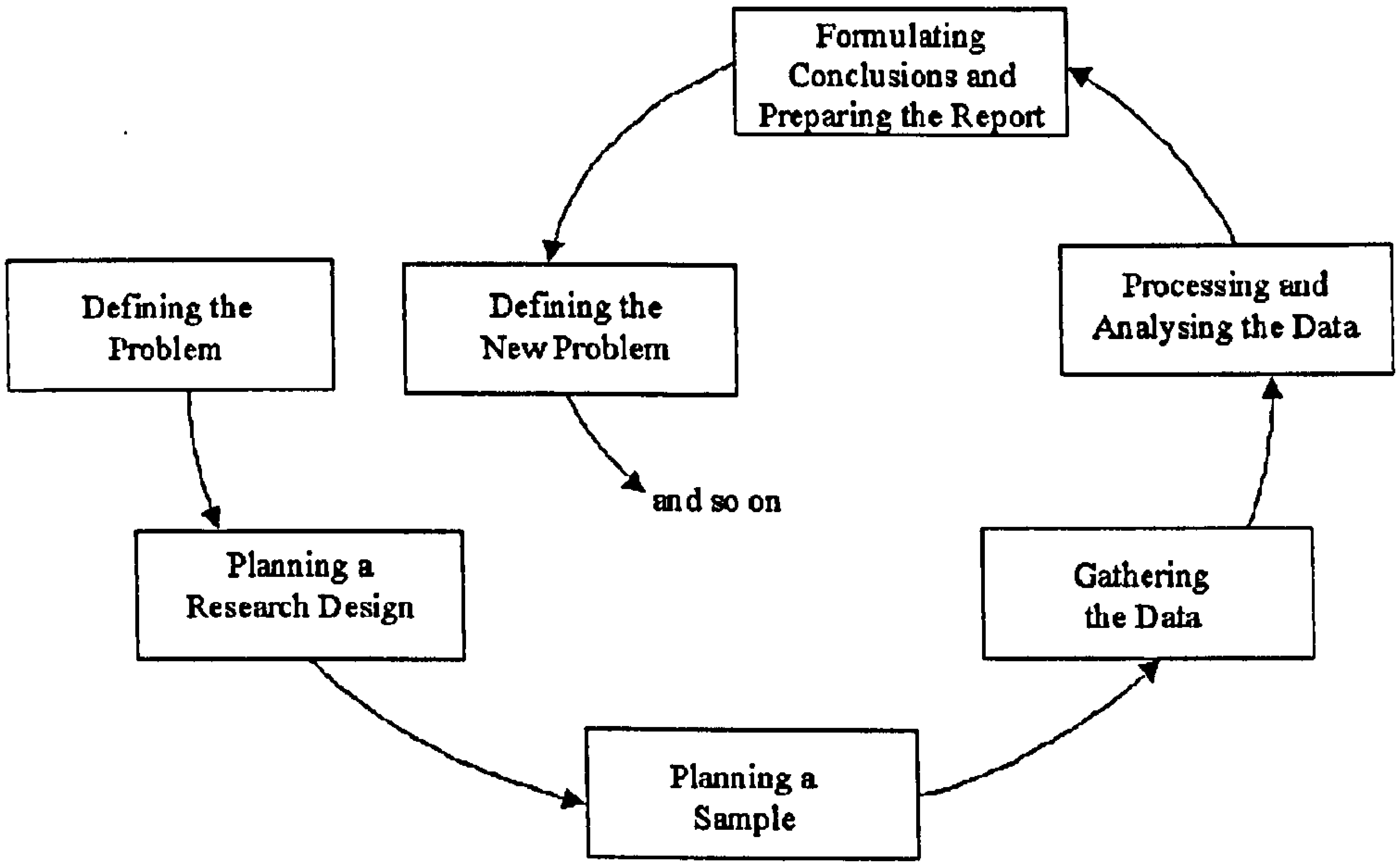
Sources: Gummesson (1991), pg. 153

Table 2.2 Positivistic verse Phenomenological Research

In summary, when all three categorisations and the six types are considered, it is obvious that they complement each other and offer different insights.

2.3 Research Process

As presented above research can take many forms, but there is a common characteristic - *systematic inquiry*. For systematic inquiry to take place, a researcher should develop plans and project management, because research, like any other project is a series of highly interconnected activities. The stages in the research process overlap continually and it is an oversimplification to state that every research project follows a neat and ordered sequence of activities. Nevertheless, research can often follow a generalised pattern. The six stages observed by Zikmund (2000) are (1) defining the problem, (2) planning a research design, (3) planning a sample, (4) collecting data, (5) analysing data, (6) formulating the conclusion and preparing the report. These six stages are shown in Figure 2.1 as a cyclical process or as a circular-flow concept, because conclusions from research studies usually generate new ideas and problems that lead to further investigations.



Source: Zikmund (2000), pg. 54

Figure 2.1 Research Process

2.3.1 Functions of Research Design

Emory (1985) defined research design as "a plan that specifies the sources and types of information relevant to the research question. Furthermore, it is a strategy or blueprint specifying the approaches to be used for gathering and analysing data" (pg. 59). From this, the major function of research design is to provide the researcher with a plan or blueprint for studying research questions. There are several decisions a researcher should consider before beginning the project. For example, the method of conduction, the data collection method, the sample size, the variables used in the survey, the goals and objectives of the research, the time frame of the project, etc. A second function of research design is to assist researchers in establishing the boundaries of research activities and hence enable the researcher to channel his energy in a specific direction. Without this outline of the research boundaries and objectives, a researcher's activities on a single project could be endless. On the other hand, with clear research objectives, a researcher can proceed systematically toward the achievement of certain goals. Furthermore, the structure provided by the research plan, enables the researcher to reach closure and consider any given project completed. The third function of research design is to enable the researcher to anticipate potential problems in the implementation of the study. A researcher should conduct an appropriate literature survey on the topic under investigation and from this review, identify new or alternative approaches to the research problem. Lastly, research design may provide some estimate of the cost involved for carrying out the research, possible measurement problems and plans for the allocation of resource such as time, material and manpower.

2.3.2 Data Collection Method

There are several conventional research methods used to answer various kinds of research questions. These research methods can be based on case studies, experiments, grounded theory, ethnographic studies, action research and surveys etc. One of the most popular research methods is the survey method, that involves contacting a sample of individuals from a larger population.

Using information obtained through questionnaires, interviews, direct observation, or combinations of these techniques, certain assumptions and hypotheses can then be tested, and several insights can be achieved regarding the respective problems under investigation. Therefore the aim of a survey is to obtain information that can be analysed and patterns extracted and comparisons made.

2.3.2.1 Advantages and Disadvantages of Surveys

The major advantage of surveys is that they are an economical way of collecting a large quantity of data. Mailed questionnaires, are commonly used as an inexpensive means of obtaining information from large numbers of people without contacting them directly. In addition to this advantage, survey results can be generalised to a larger population because of the sample size of the survey tends to be large. Another advantage of using a survey is that researchers have a degree of control over the research process. They can choose different techniques, such as observation, interviewing, and/or questionnaires in their survey methods. Also, researchers have a greater degree of control over the research variables as the structure of the survey is generally tailor made to suit the research objectives.

The disadvantage of using survey methods, especially questionnaires is that they can only reflect superficially the characteristics of the populations' understudy. This is mainly due to the limits of information that can be collected from the respondents and that the results obtained can sometimes be delusive. Another disadvantage is that researchers have little or no control over the response rate. Lastly a significant disadvantage is that researchers must be capable of designing an effective survey to ensure governing variables are used, appropriate piloting of the survey and analysing results.

2.4 Research Design of the Present Research

A research scheme was developed to guide the conduct of this research. Similar to the research model suggested by Graziano and Raulin (1989), several phases could be determined from this research process. However, these stages were slightly different from the ones stated in Chapter 1, and consist of five major phases: needs analysis, review of relevant concepts, formulate fitness model, application of model and review and conclusion. These stages are outlined below.

1. **Needs analysis** - identify certain strategic problems that manufacturing organisations face.
2. **Review of relevant concepts** - examine the relevant concepts and tools that could be used to resolve the problems.
3. **Formulate fitness model** - identify the concepts and elements for the fitness model.
4. **Application of model** - construct the fitness model for a population of manufacturing organisations.
5. **Review and conclusion** - review the insights learned from the construction of fitness model.

Table 2.3 shows the research activities and their outcomes at the various stages of this research.

Stages	Research Activities	Outcomes
Needs analysis	Understanding the manufacturing problems	Identification of research objectives - to define manufacturing fitness
Review of relevant concepts	Literature review on complex system theory. Literature review on fitness landscape theory	Identified potential tools - Fitness landscape theory Identified potential applications of fitness landscape theory Identified needs to develop fitness function for manufacturing organisations.
Formulate fitness model	Literature review on evolutionary and fitness concepts in biological, organisational and manufacturing environment Literature review on manufacturing capabilities. Data collection	Defined organisational and manufacturing fitness Identified the cumulative model Identified secondary data source - Mx2000 competition
Application of model	Searching for ways to make the fitness comparison Compare manufacturing fitness of a population of manufacturing organisations	Formulated fitness calculations Produced manufacturing capabilities mapping
Review and conclusion	Examining of fitness mapping Reviewing the research process and its objectives	Identified the validations, implications and limitations of model Appraisal of the research method Achievement of research objectives Suggestions for future researches.

Table 2.3 Scheme of work for this research

2.4.1 Needs Analysis

An overview of manufacturing was undertaken to assess the strategic needs and problems faced by UK manufacturers as stated in Chapter 1. Manufacturing organisations are always facing change and improvement according to the technological, operational and economic drivers that are in place. The key to successful survival is for a manufacturer to formulate and implement appropriate strategies. However, there is significant debate about which manufacturing capabilities to employ. This issue is at the heart of this research and motivated the need to examine new managerial tools to help formulate solutions.

2.4.2 Review of Relevant Concepts

Once the objectives were defined, the research proceeded to explore potential techniques and theories which would be the basis of the solutions. Chapter 3 introduces and evaluates complex systems theory as an appropriate body of knowledge. From this theory, several metaphors and tools were identified. Established tools include: chaos theory, genetic algorithms, edge of chaos, self-organising systems, fitness landscape theory, etc. This thesis evaluates and justifies fitness landscape theory as an appropriate and novel approach for formulating manufacturing strategy. As described in Section 2.4.3 a detailed literature review of fitness landscape theory was carried out to acquire the necessary knowledge to translate and develop this theory into a manufacturing context.

2.4.3 Formulate Fitness Model

Before a model and definition for manufacturing fitness could be defined, the evolutionary and biological concept of fitness was assessed. This biological concept has been in existence for 140 years, since Darwin proposed the idea of "survival of the fittest" (Gould, 1991). From the biological research that has taken place, this thesis then evaluated the definitions and concepts that have been produced for organisational and economic studies and concludes that there is currently no formal definition of organisational fitness. From this work, this research sets out a preliminary definition of organisational fitness and then manufacturing fitness.

To develop the definition of manufacturing fitness, another literature review was undertaken on the subject of manufacturing capabilities. This review identified two contradictory models the cumulative model and the trade-off model. Using the arguments that support both these models, a fitness model for manufacturing was developed.

The next stage was to focus on data collection in order to construct the fitness model. Working in collaboration with the University of Warwick and the Mx2000 competition for manufacturing excellence, secondary data sources were used.

2.4.4 Application of Model

In order to obtain a comprehensive view of the performance of organisations, multi-variable comparison tools such as Data Envelope Analysis (DEA) (see for example, Cooper et al., 2000 or Coelli et al., 1998) and operational rating analysis (OCRA) (see Parkan and Wu, 1999; Parkan and Wu, 2000) were assessed. Based on these multi-variable non-parametric tools, a manufacturing fitness calculation was formulated for each sample organisation. By linking a manufacturer's fitness to the manufacturing capabilities employed, a manufacturing capabilities fitness was composed, and a mapping for manufacturing capabilities was produced. This map describes the paths and the sequences of different manufacturing capabilities and their relation to optimal fitness.

2.4.5 Review and Conclusion

With this fitness map of manufacturing capabilities, the validity, utility, value and limitations of such a model was examined. The thesis concludes by reviewing the research process, novelty and conclusions. From this review, the thesis provides suggestions for future work.

2.5 Data collection methods for Research

Many studies attempt to conduct a new survey in order to gather the data needed for the study. These data are known as *primary* data as they are designed specifically for that research purpose. Few researchers consider the possibility of re-analysing data that has already been collected, and is known as *secondary* data. Secondary data are defined as data gathered and recorded by someone else prior to and for purposes other than the current needs of the researcher (Zikmund, 2000, pg.124).

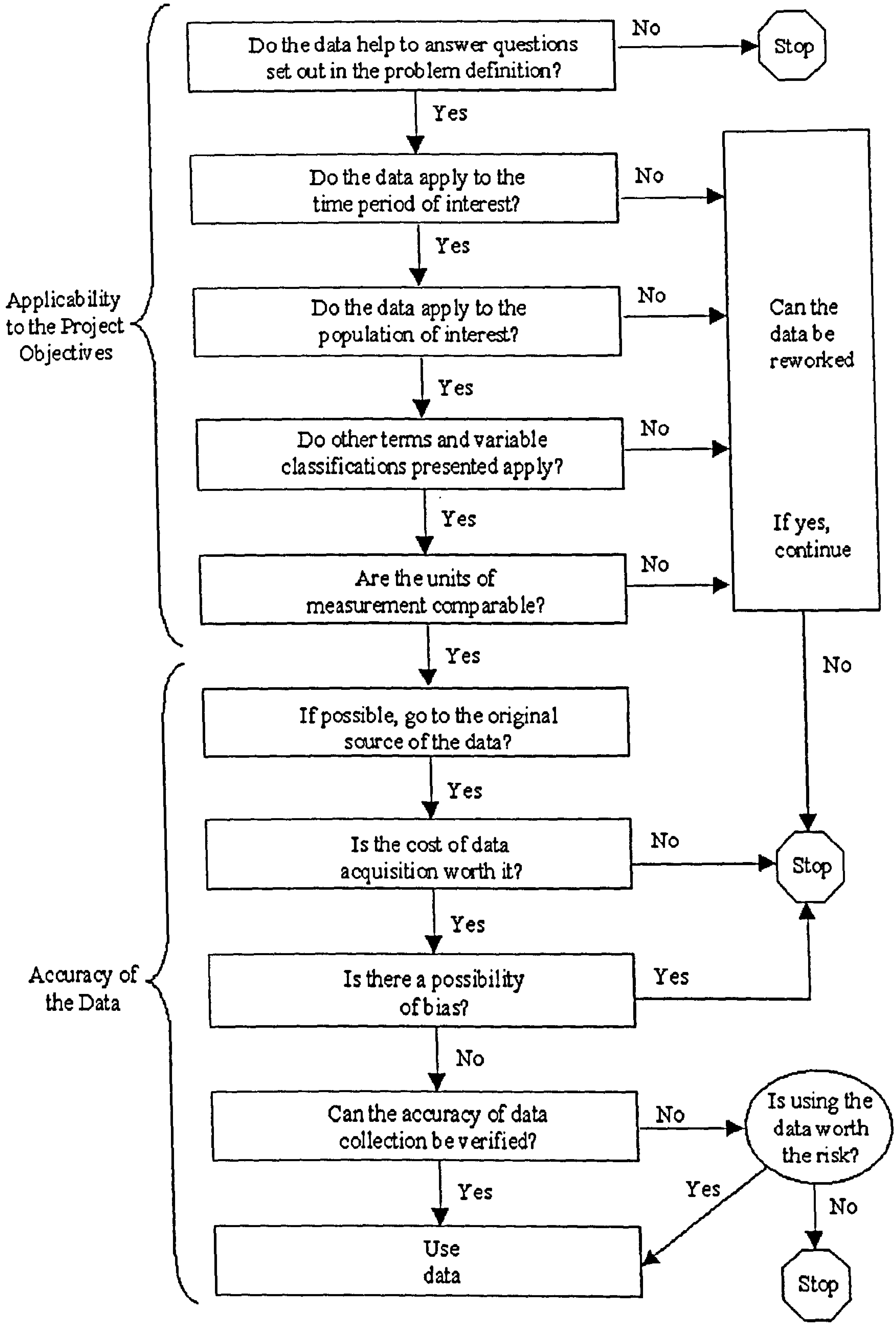
There is practically no boundary to the sort of materials for secondary data. These data can be of private (e.g. personal letters, diaries, logs, appointment books, etc.) or official sources (Census Bureaus, national statistics offices, etc.). Regardless of form, there are three common characteristics of secondary data. First, it is ready-made. Secondly, it has been gathered using a process which the researcher has practically no original control over. This is because the form and the content of secondary data is shaped by the original institute/owner/researchers that gathered the data. This feature can limit the overall scientific value of the secondary data. However, secondary data can also provide information that might otherwise have been impossible to gather. Finally, the researcher using the data does not have to engage with the respondents or subjects during the period when the data was collected. This however, means that the researchers do not have access to the respondents or subjects of the investigations.

2.5.1 Suitability of Secondary Data

In order to establish and compare the fitness of different manufacturing companies that deployed different manufacturing capabilities, the Manufacturing Excellence Award (Mx2000) database for year 2000 was used. This database contained information on 27 manufacturing plants participating in the competition which consisted of five category awards and two overall awards for manufacturing excellence. Mx2000 was organised by the Institution of Mechanical Engineers and co-sponsored by KPMG and the DTI's Foresight Programme, with the support of the Warwick Manufacturing Group. Each company that took part in this competition had to complete a 21 page questionnaire, in order to provide a comprehensive profile of capabilities and performance. A detailed introduction to this competition is presented in Appendix A.

To recap, this research used the Mx2000 data in order to construct a fitness model. In other words, this research used secondary data and therefore, a discussion on the suitability of this data is given.

The Mx2000 survey was not tailor-made to suit the objectives and purposes of this research and therefore an evaluation this data versus new primary data was undertaken. Zikmund (2000) presents a series of questions that should be asked in order to evaluate secondary data (see Figure 2.2). By following this evaluation the Mx2000 data was considered to be appropriate for the objectives of this research.



Adapted from Zikmund (2000), pg. 127

Figure 2.2 Evaluating Secondary Data

2.5.2 Variables and Performances

The next task was to determine the relevant questions from the Mx2000 questionnaire. Using a process similar to that used by Noble (1997), this study used composite variables so that no single question could capture adequately the multi-facets of each manufacturing capability. The Mx2000 questionnaire was filtered according to the literature review and findings of Chapter 6. By examining the specific manufacturing characteristics surveyed by the Mx2000 questionnaires, relevant manufacturing capabilities for the sample population of manufacturing organisations could be established. These questions are presented in Appendix B. There are five questions each for the capabilities *flexibility* and *delivery* and seven questions for the other two capabilities, : *quality* and *cost*. For each question there is a scoring system based on a self-evaluated 5-point table.

In order to measure the fitness of a manufacturing company, it is important to note that the company is a co-evolving system within a bigger system (industrial ecosystem). It is also important to note that the action of each company within this system affects the system. This is because the fitness of a company is not only determined by its own performance, but also by its performance relative to that of the competitors. Thus, the fitness of one company is a function not only of its own characteristics and behaviour, but of the characteristics and behaviour of all of its rivals in that population (Metcalfe, 1998). Therefore, the fitness measurements of organisations in this study are a ratio of one organisation against another.

The Mx2000 survey companies disclosed data on past performance (up to 3 years). Although this data was gathered from the participant companies independently, it was studied and verified by the competition organisers. The performance measurements used in the survey (sale per employee, Economic Value Added, profit, etc.) were chosen using arguments in accordance with the views presented in Chapter 5 and Chapter 6.

2.5.3 Reliability and Validity of Data

The structure of the Mx2000 questionnaire was compiled and designed by several academic and industrial authors. This multiple author approach to the design of the questionnaire helped reduce the measurement bias and provide several opportunities to pilot the questionnaire. To help validate the survey data and avoid potential deception by the survey respondents, visits were made to the organisations.

2.6 Conclusion

This chapter introduces the reader to the research methodology and process used throughout the thesis. This research adopted a systematic investigation into a research problem – *manufacturing strategy formulation*. Developed from a general research model, this research can be divide into five stages: needs analysis, review of relevant concepts, formulate fitness model, application of model, and review and conclusion. For each stage, the research activities and its outcomes are discussed. Lastly the data collection methods and the variables extracted have been explained.

Chapter 3. Complex Systems Theory

A new set of theories is beginning to outshine traditional approaches to systems science. The concept and study of non-linear dynamic systems as opposed to static and predictable systems, has captured the attention of both the academic and business community. This approach to systems study has been labelled the *science of complexity theory* or *complex systems theory*.

This chapter begins by introducing the orthodox approach to studying systems. This approach is then compared with the complex systems approach and the key features of a *complex adaptive system*. These features are explained and related to manufacturing issues (strategic and operational) and it is concluded that manufacturing organisations are certainly complex adaptive systems in terms of constituents, architecture, behaviour and transformation functions. The concluding section of this chapter contains and discusses some of the tools and concepts that can provide insights to manufacturing problems and issues.

In summary, this chapter will:

- Introduce the traditional approach to studying systems and the limitations of this approach.
- Contrast the traditional approach with the complex systems approach.
- Present and explain how complex systems theory relates to manufacturing issues and problems.
- Describe the key metaphors, theories and tools and constitute complex systems theory, including fitness landscape theory.

3.1 Orthodox Science

Science seeks explanation of how the world functions. Traditional approaches to this issue have been based on a reductionism philosophy that believes that in order to understand large complex systems they should be reduced, decomposed or disassembled to simpler indivisible parts. In physics, these parts are called quarks; in chemistry they are atoms and molecules; in biology the focus becomes the cells and genes. The promise of reductionism gave rise to analytical thinking that sought to explain. This thinking consists of three steps. First, researchers look at the subject of interest and disassemble it into independent and individual parts. Then the behaviour of these parts are studied and explained. Finally, an explanation of the whole is deduced by combining these partial explanations of its parts. It is assumed that the solution of the whole is the sum of the solution of the independent parts. However, most systems, if not all, are synergistic, in other words, the systems have more properties than the sum of the properties of the individual parts.

The relationship between the parts is assumed to be explainable by using one ultimately simple relationship, that of cause and effect. In other words, a difficult non-linear problem is reduced to simpler linear ones in order to analyse the problem. Since the only explanation of an effect is its cause, nothing else except this cause is required to explain the phenomenon. As a result, the explanation gathered is unconnected to its context and environment. For example, scientists studying gravity in the 16^{th} century, disregarded the observation that a feather does not fall with the same speed as a ball, which is a result of the air resistance. As such, laboratories with specially designed environments were set up to exclude the environmental effect on the subjects in studies. Since the effects are solely determined by causes, the perceived view of the world was deterministic and mechanistic. Sir Isaac Newton's formulation of an orderly and predictable universe led the vision for traditional science. His studies of planets and their orbits, observed the consistency, stability and the order of these objects in motion. Using Newton's mathematical laws, astronomers predicted the future motion of the Solar System with high degrees of accuracy and reliability. Through this triumph, classical physics reduced the unknown universe into a couple of governing principles. This led the view that the world was an orderly machine with clockwork-like behaviour that functioned in a deterministic and predictable way.

3.2 Complex Systems Theory

The cause and effect approach described above, may be useful for understanding simple systems, but using it to explain social and economic systems is unsuitable and inadequate. For example, in the case of the video player/recorder market, the dominant system at present is VHS. This can be seen as an effect. In order to find the cause of this effect, one has to look back to the late 1970s. Two player/recorder systems, VHS (invented by JVS) and Betamax (invented by Sony) emerged from a myriad of confusing and incompatible video formats. There were VCR and VCR Long Play from Philips, SV (Super Video) from Grundig, LVR (Longitudinal Video Recording) from Toshiba, and Video2000 a collaboration between Grundig and Philips. Betamax lost the battle as soon as VHS stole a slight but visible advantage. This advantage was then translated into an increasing propensity for consumers and retailers to favour VHS, which in turn led VHS to dominate the video market. In this simple case, there is no clear boundary of causes as both products had the same chances of success, although it is important to note that Betamax was said to be technically superior to VHS. The outcome is not predictable.

Using traditional methods, there are many interesting systems that are difficult to describe, understand, monitor and control. This difficulty mainly arises from the non-linear interactions among the system components. They are characterised by the interaction of individual agents or elements whose collective behaviour forms the basic characteristics or building blocks of a higher system level. The simple linear systems, so thoroughly studied by Newtonian science, are the exception, rather than the rule. This planet and its biological, social and technical systems are governed by complexity and chaos. Recent discoveries from the natural sciences have provided a new momentum and the insights that are necessary to understand the complexity of the world and natural processes. Viewing the universe as a turbulent and disorderly system, has led to the promotion of a new science, labelled the "science of complexity" or "complex systems theory". This science focuses on the study of complex systems. These interesting systems have attracted the attention of leading thinkers, including several Noble Prize laureates such as Murray Gell-Mann and Illya Prigogine. They come from a very diverse range of fields such as biology

(Stuart Kauffman), physics, chemistry, economics (Brian Arthur), physics, mathematics (John Casti), engineering and computer science.

Before discussing complex systems, the concept of the system has to be discussed first. The word "system" has evolved from an early Greek term which meant "organised whole". It also links to a Latin medieval usage, meaning "the universe". Recently a system has been defined as "*a group of component parts that individually establish relationships with each other and that react with their environment both as individuals and as a collective*" (Obloj and Cavaleri, 1993, pg. 13)

Casti (1998) suggested that all systems could be classified into two categories, *simple* and *complex* (see Figure 3.1). Simple systems are only found in the school for teaching purposes i.e. to elucidate the basic principle or theory. As for the complex ones, they can be divided into two further classes, *non-adaptive systems (~A)*, and *complex adaptive systems (CAS)*. The rules of non-adaptive systems do not change. Examples include 'dead' systems found within physics, astronomy, chemistry, etc. In other words, they are linear systems where the rules do not change or they change at a very slow rate. On the other hand, a CAS has rules that change through learning, adaptation and the process for survival. These systems are 'alive' and include biological systems (evolution, immune systems), economic systems (stock market) and psychological systems.

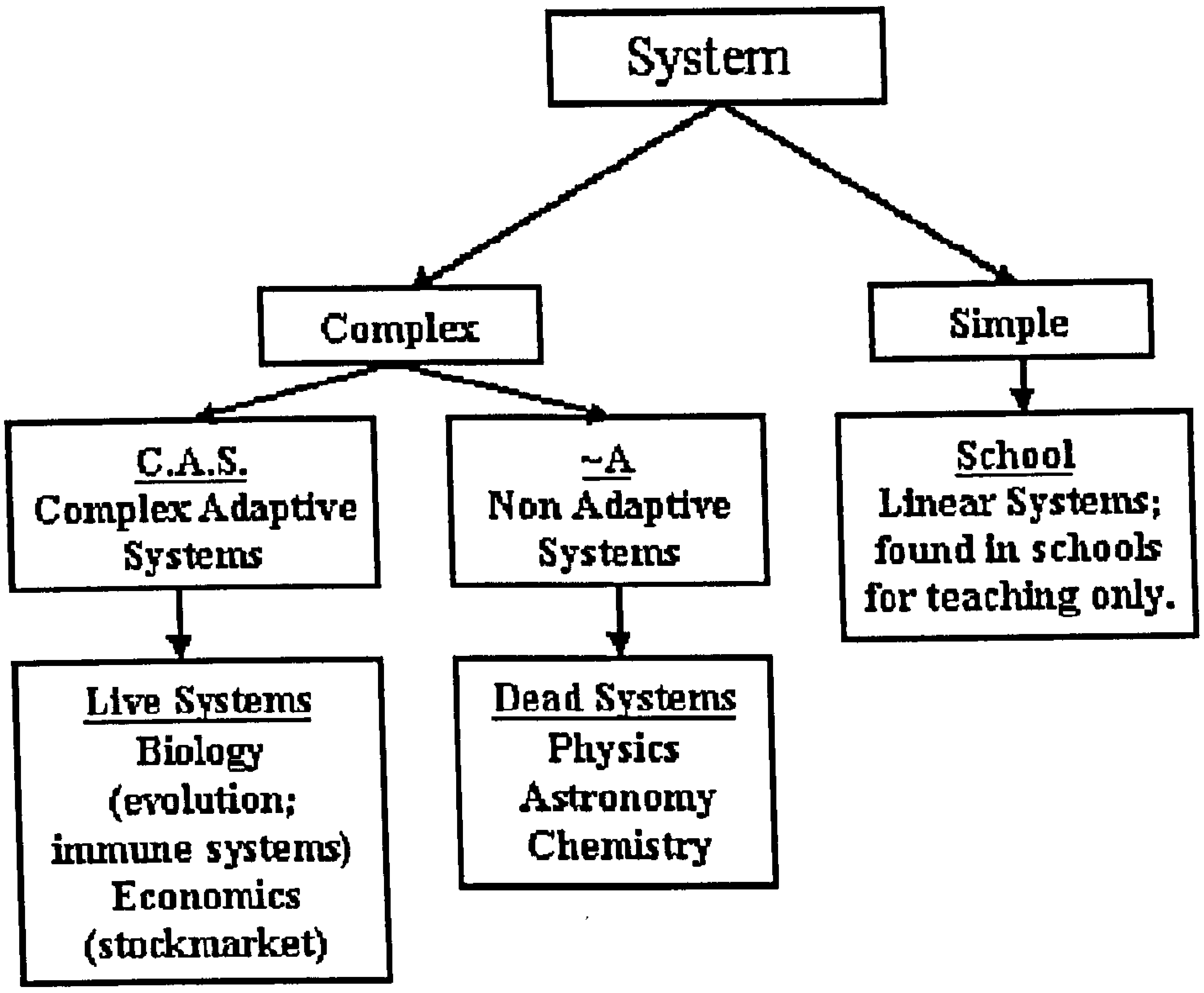


Figure 3.1 Classification of System

3.2.1 Characteristics of Complex Adaptive System

A complex adaptive system (CAS) is defined by Mitchell (1993) as:

> "[I]n which complex behaviour of the system as a whole emerges from the interaction of large numbers of simple components, and in which the system is able to adapt --- that is, to automatically improve its performance (according to some measure) over time in response to what has been encountered previously." (pg.1)

From this definition, there are several important characteristics of a CAS:

Firstly, each system is a network of many individual active elements, which are generally called *agents*. They interact in various ways, using their own internal rules, states, and strategies of the past experience. These internal rules are termed: *schemas*. Agents by themselves are considered to be 'simple' with reference to the system. For example, in the brain, the agents are nerve cells. In an economy, the agents include people and households. In business cycle, the agents include companies. In a manufacturing company, the agents include workers and machines.

Secondly, CAS have the ability to learn and hence adapt to a new dynamic environment. The system is constantly revising and re-organising its agents as experience is gained from past interactions. From this learning, the system will change its strategies towards the future by changing its schema. This characteristic is very important, as this will help the system to gain more success. Without this adaptability, the system could face extinction. For example, a company will promote an individual if he/she is doing well or dismiss someone whose performance is not as good. The brain will strengthen or weaken the connection of a nerve cell as it evolved by learning. A manufacturing company will invest more in a production line that yields profit.

In addition to these two interesting characteristics, Waldrop (1994) also noted that complex adaptive systems will in one way or another try to predict the future and then react to the situation regardless of the actual effect on the environment. A CAS is constantly making predications based on internal models of the environment. This prediction is based on the internal and external assumption of the agents relative to the environment. For example, in a recession, one would try to delay buying new items or avoid unnecessary spending which in turn extends the recession. The prediction of an oil shortage will see nations rush to store up their oil supply and push the situation worse as the price increases with higher demand. The forecast of a share-crash will prevent any buyer entering the market and thus shares will plunge further.

Waldrop also suggested that a CAS has many levels of organisation. The agent at one level will be the building blocks for a higher organisation. A group of people will form a department, several departments will form a company, many companies will form a business cycle, a string of business cycles will form a national or regional trade.

Casti (1998) also noted that the agents only receive and process local information that is available to them. This view is different from the classic assumption that the 'ideal world' provides all information equally distributed to all involved.

Finally, complex adaptive systems usually have many niches, or pockets of opportunity. Another adapted agent can then fill these niches. This very act of filling the niches will open up more niches for other agents. In the event of a factory employing more workers, then these workers could purchase more sandwiches from the local café, thus securing or even increasing employment levels at that café.

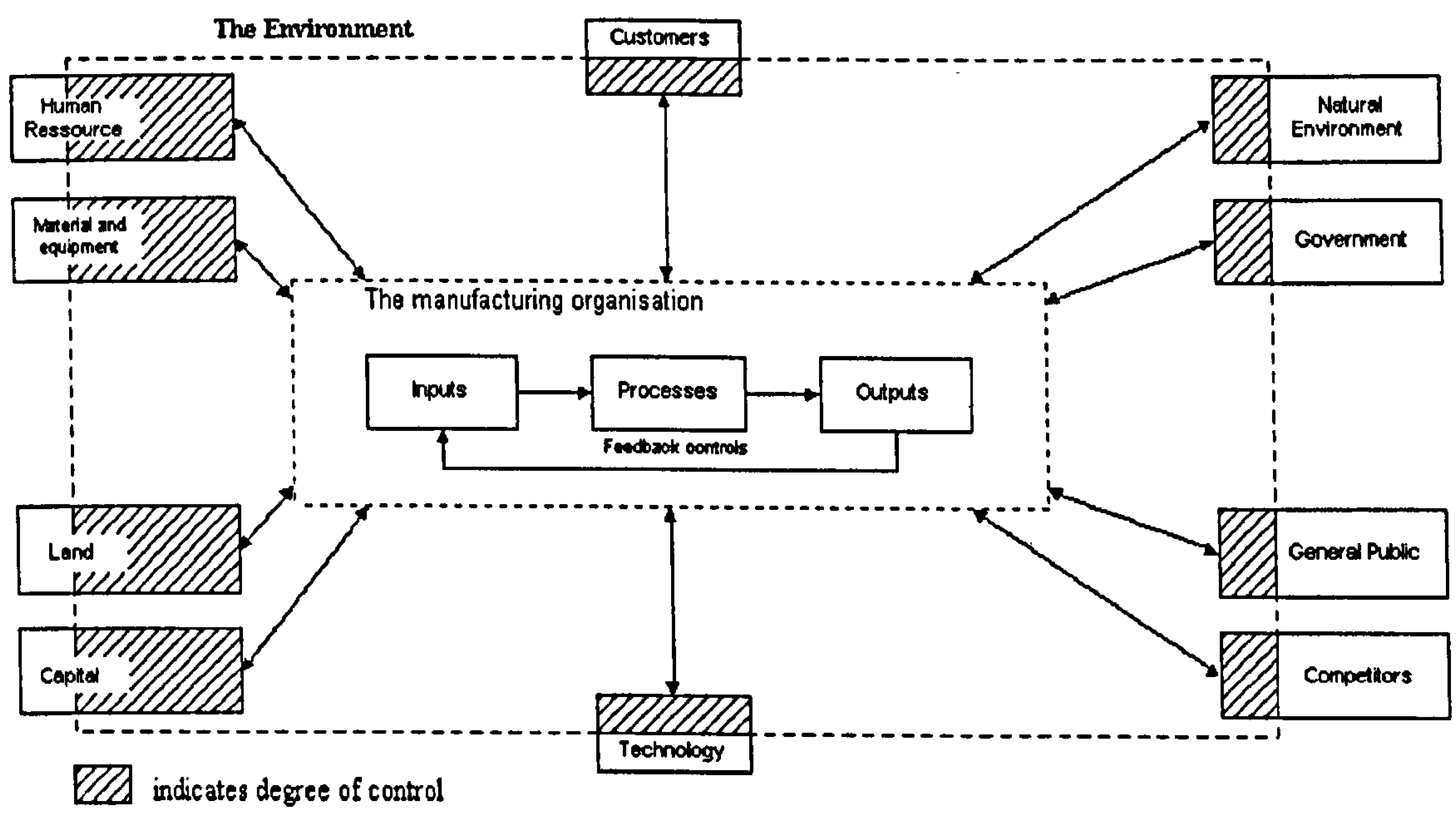
3.2.2 Manufacturing Organisation as Complex Adaptive System

McCarthy et al. (2000b) presented a simple systems diagram of a manufacturing organisation (shown in Figure 3.2). The manufacturing organisation can be viewed as an aggregation made of several interconnected components that interact within and beyond its organisational boundary, and where each component contributes toward a common goal which is to transform raw material into marketable product. McCarthy et al. then go on to discuss manufacturing organisations as a complex adaptive system. Using a systems definition, a manufacturing organisation consists of:

1. *Assemblage.* A number of distinguishable elements (people, machines, departments, components, sub-systems, etc.) can be identified.
2. *Relationships.* Simply bringing the elements together results in a "group" rather than a system. For a system to exist the elements must have relationships. The materials and resources within a manufacturing system must interact to produce a product. *Materials + Resources = Products*
3. *Objectives.* Manufacturing systems have multiple objectives, which can result in conflict. The purpose of a manufacturing system is to organise elements and sub-systems to satisfy certain objectives. They will vary from organisation to organisation, but are generally considered to be of those listed below:
   - Produce products within defined process and design specifications.
   - Produce products within defined time scales.

- Produce products to specified levels of quality.
- Produce products to a cost acceptable to customer and company.

4. *Adaptive.* A manufacturing system must operate and adapt to market, economic and political conditions in order to survive and stay competitive.



Source: McCarthy et al. (2000b), pg. 45

Figure 3.2 Manufacturing Organisation as Complex Adaptive Systems

If a manufacturing organisation is now related to the key concepts of complex adaptive systems (agents, schemas and predictions), the following statements can be made:

- *Manufacturing Agents*: Any entity (person, machine, supplier and customer) within the system that can produce an effect (new orders, machining, break downs, unloading, etc.) Agents have a degree of autonomy (machines are autonomous as they break down on their own!). Manufacturing organisations consist of a multitude of agents that tend to be independent in their operations and behaviour, despite the connections that exist among them and efforts by managers to fully control them. In summary agents are characterised by:
  - Their internal states, such as 'operating' or 'idle' (e.g. the status of a machine or worker).
  - The input they receive and the output they generate (e.g. processing raw material or information).

- The process that allows them to make simple decisions (e.g. the functional task that carries out the process – machining, scheduling, ordering, etc.)
- *Manufacturing Schemas*: A characteristic of the interaction of the agents is the creation of *schemas* inside the system. Schemas are the rules or procedures that can be specific to individual agents (e.g. the mentality and attitude of individual workers and machines) or can be shared by two or more agents (e.g. this organisation operates a make to order system).
- *Manufacturing Predictions*: This is when manufacturing organisations attempt to anticipate the future. It includes forecasting activities such as diagnostics for maintenance, and statistical process control for quality and sales forecasting.

With the above discussions, it is clear that manufacturing organisations are complex adaptive systems, as they learn, adapt and evolve over time (Kauffman and Macready, 1995). Although, McMaster (1996) argued that the organisation should be called a complex *intelligent* system, as

> *"It is only through intelligence that an organisation can grow, adapt, and survive. An enterprise is not considered an organisation until it is operating on its own intelligence." (pg. 9)*

There are now many studies that apply the complex systems theory to organisations (McKelvey, 1997), family care practices (Miller et al., 1998) and others, but it is has not been adequately developed or applied to the area of manufacturing. The novelty of this thesis is an attempt to address this issue.

3.3 Complex Systems Theory (Ideals, Metaphors and Tools)

In the past, it has been very difficult to analyse complex adaptive systems using standard mathematics. Most conventional methods like calculus or linear analysis are suitable for unchanging systems in a fixed environment. To have a better understanding of the complex adaptive system, one has to use mathematics and computer simulation techniques which are capable of simulating the interaction between the internal agents as well as the changing environment caused by these interactions (Ruthen, 1993). Holland (1992) also noted that since the environment is always changing and adapting, it is pointless for the agents to optimise their function or fitness. The space of possibility is too large and there is no practical way of finding the optimum. The most agents can do, is to change and improve themselves against what other agents are doing.

This section of the thesis seeks to understand how manufacturing organisations (identified as being a complex adaptive system) can benefit from the studies of complex systems theory. It describes the primary metaphors, tools and theories that constitute complex systems theory. The first five sections are adopted from McCarthy et al. (2000b).

3.3.1 Memetics

Memetics is the study of memes. The name originated from Dawkins' attempt to characterise the crossing of "memory" and "genes"(Dawkins, 1989). A meme can be thought of as a unit of knowledge (e.g. an idea, a concept, a form of technology), which has evolved. To manufacturing organisations, memes are analogous to genes in biological organisms. It is like an *organisational gene* or *blueprint,* which contains a manufacturing organisation's history, its past experiences and the resulting learning process. Memes transmit instituted past ideas and concepts to improve new working practices. De Geus (1988) suggests that *memes* enable organisations to learn and are the characteristics of organisational culture. Thus, one of the main applications of memetics to manufacturing is the ability to understand the *knowledge management* processes that exist within the organisation.

In an engineering design context, memes can be the design knowledge that accompany designed artifacts as they evolve. For instance, if we consider computational devices, there are a host of ideas and concepts which have accompanied the evolution of the abacus, to Babbage's first computing device, to the first mainframe computers, to desktop calculators, to the first personal computers, to the latest palmtop computers. As each piece of technology has evolved, there is accompanying design knowledge (a meme).

Understanding how memes are transmitted between generations of engineering designs, or types of manufacturing organisations is a knowledge management issue. The model that is used to understand the knowledge processes is based on three criteria: *heritability*, *variability* and *selection*.

- *Heritability* means that the information must be transmissible in some way. In the modern world, this criterion is easily satisfied, as information is documented and published via books, television and the Internet. The transmission of information can take many forms, e.g. reading a book, a training course, an informal conversation between two people and formal education at schools and universities. A classic example of heritability is when people move from one job to another in a different industry. If a person has worked for twenty years in the mining industry and then joins the automotive industry, that person takes with them twenty years of experience and ideas (memes) to their new job. The important thing is that this person will transmit or infect some of their new colleagues with their memes, in the same way that this person's new working environment will change them.
- *Variability* is the notion that there is scope for difference. Memes do not replicate perfectly. In the above example, even though the worker takes with him experience and ideas to his new job, much of it will not be relevant to the new job and will be forgotten or discarded.
- *Selection.* When memes are popular, successful or competitive, there is a tendency for them to replicate. That is, if an engineering design is successful it will be imitated. In terms of organisational philosophy the success of the Toyota Production System spawned a host of imitators across the world. The *variability* process created different versions of this new way of manufacturing. European and North American systems were slightly different from the original Japanese system, due to the cultural and political differences that existed in these continents.

3.3.2 Self Organising Systems and Evolutionary Models

Self-organisation is the evolution of a system into an organised form in the absence of external constraints, and it can only take place when the system is near the edge of chaos. For organisations, it is believed that there are five levels of self-organisation that exist. Table 3.1 presents each level in terms of the nature of the processes taking place within the organisation, the ways in which decisions are made, the types of trade-offs taken into account during decision making, the attributes of the organisation's knowledge and the types of agent available to the organisation.

Self-Organisation Level	Process	Decisions	Trade-Offs	Knowledge	Agents
Consciously competent	Enterprise always improving	Value-based	Mutually beneficial	Evolutionary relationships	Dynamic and changing
Quantitatively guided	Based on statistics	Data based	Anticipated	History and simulation based	Quantified
Guided	Units that work	Rule based	Objective	History and team based	Leveraged
Conscious	Loyal to team plan	Integrative	Visible	Team based	Common and public
Unconscious	Agent ad hoc	Reactive	Unclear	Personal	Private

Adapted from Kelly and Allison (1999), pg. 140

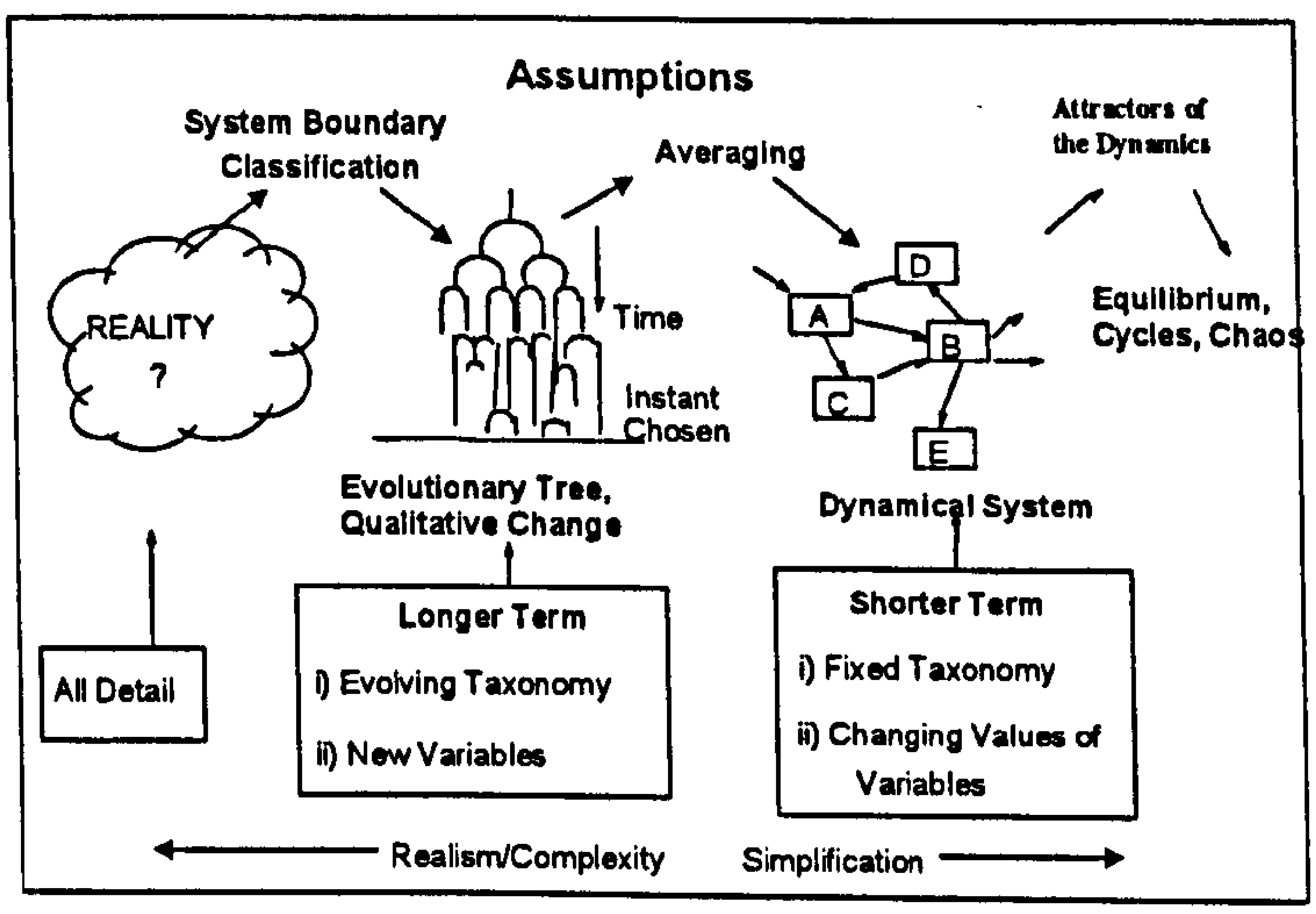
Table 3.1 Levels of Self-Organisations.

Although Table 3.1 presents the different forms of self-organisation that might exist within organisations, how do we model self-organising systems and what will these models tell us? Allen (1998) describes a self-organising evolutionary model by discussing the model's ability to represent decisional situations. For any decisional situation there is a single past, but the possible futures are multiple and thus managers that are involved in a decision making process need to address the following questions:

- What is going on?
- What might happen if I do nothing?
- What outcomes are possible?
- Which outcome do I prefer?

A self-organising model is able to reconfigure itself and innovate. It is a model that is capable of evaluating alternatives, learning and exploring future scenarios and therefore provides significant value in answering the above questions. In order to construct these models, some steps have to be taken to reduce system reality to mechanics. These are shown below and in Figure 3.3:

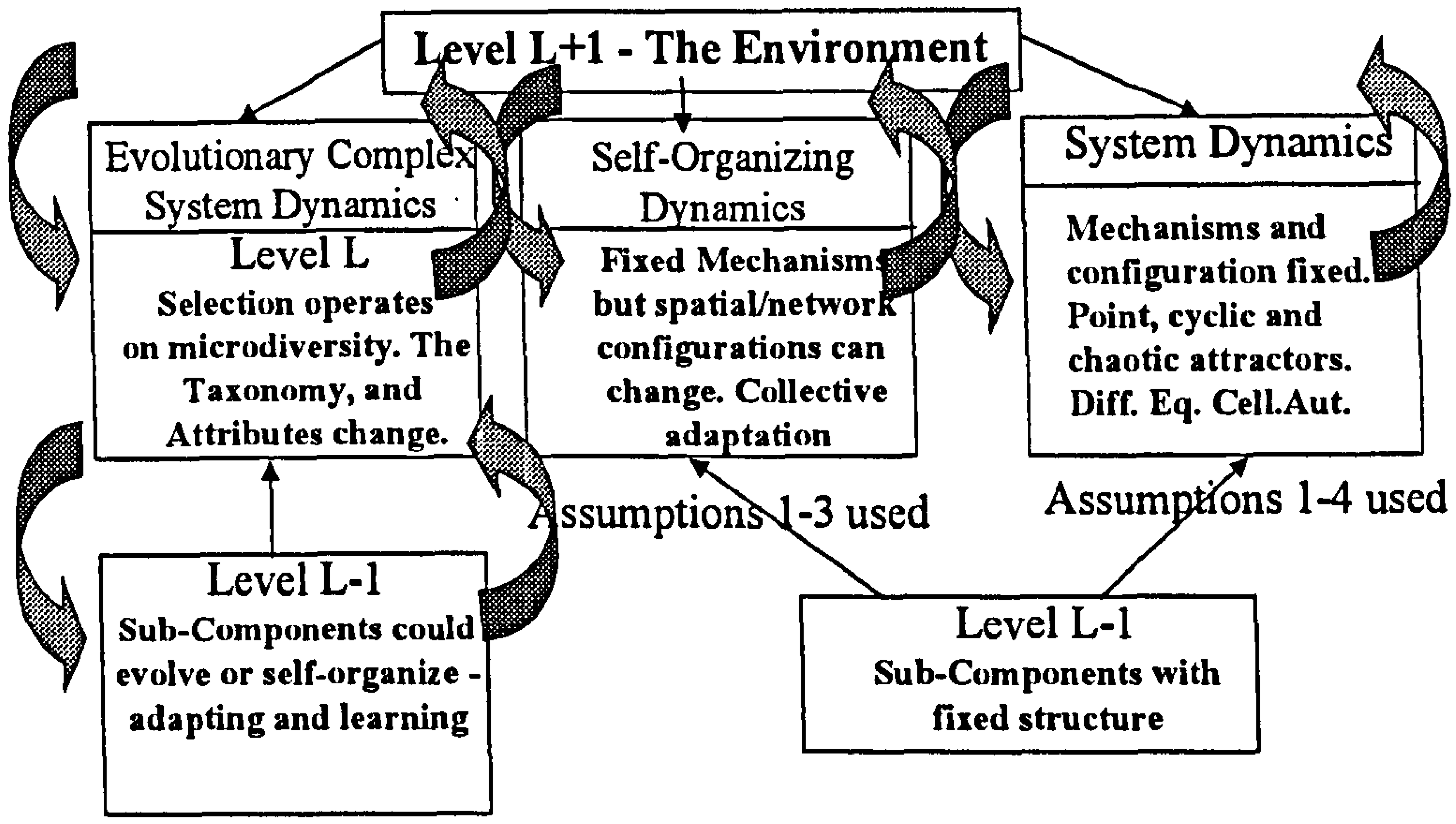
1. Assume a system boundary along with a description of its contents.
2. Carry out a qualitative analysis in order to classify the system contents.
3. For each classified group, identify an average or stereotypical behaviour.
4. Identify the underlying processes and characteristics of the system, which create this stereotypical behaviour.



Source: Allen (1998), pg. 69

Figure 3.3 Reducing complexity to simplicity

By considering steps 1 2, 3 and 4, the model is capable of representing equilibrium, chaos and deterministic non-linear system dynamics. By considering steps 1, 2 and 3, the model will be capable of representing the characteristics of self-organising systems. By considering only steps 1 and 2, the models can represent evolutionary complex systems. These are systems that contain adaptive learning processes and can change qualitatively. Finally, by considering none of the above steps the models created will be evolutionary models, in which there are endogenous dynamics of micro-diversity changing the taxonomy over time in order to explore new dimensions of the attribute space. See Figure 3.4.



Source: Allen (1998), pg. 80

Figure 3.4 The general structure of models

3.3.3 Cladistics

Cladistics is a method that has been used to study different manufacturing strategies and the evolution of organisational forms. It is a classification method used primarily in biology to study diversity by examining the evolutionary relationships between entities with reference to the common ancestry of the group. The output of a cladistic classification is a cladogram, which is a tree-like diagram that represents different "breeds" of manufacturing organisation along with their defining characteristics. The value of this classification method is the information contained within the diagram. It provides a transparent snapshot of different manufacturing strategies, along with information about how to formulate each strategy and move from one strategy to another. As reported by McCarthy et al. (1997) and McCarthy et al. (2000a), this system of coordinating information has application and value in the areas of change management, benchmarking, strategy formulation.

3.3.4 Intelligent agents

There is no unified definition of the term *intelligent agents* but it is linked to the term *adaptive agents*. Whereas, an adaptive agent has operating states, inputs and outputs and a degree of decision-making, an intelligent agent as defined by Wooldridge and Jennings (1995) is some form of computer program or computational system capable of flexible autonomous action in order to meets its objectives. Wooldridge and Jennings refer to the flexibility of such a system as:

- *Responsive*: agents should perceive their environment (workers and their departments, cells or assembly lines) and respond in a timely fashion to changes that occur.
- *Proactive*: agents should not simply act in response to their environment, they should be able to exhibit opportunistic and goal directed behaviour, i.e. they are able to take the initiative.

Several initiatives have used intelligent agents (also known as *agent based systems* or *intelligent systems*) to help manufacturing organisations continually change, adopt new technologies, create new structures and manage new working practices. For an agent-based system to help manufacturing organisations in this way, the system itself must be capable of self-reconfiguration and change. Manufacturing strategies that adopt such systems to help new product development and rapid market responsiveness are known as *intelligent manufacturing* initiatives. For a state-of-the-art survey on how intelligent manufacturing initiatives have been adopted by industry, the reader is referred to Shen and Norrie (1999).

In summary, the intelligent agent approach places importance on the "behaviour producing" aspects of a system, rather than "information structure" aspects of a system. The behaviour of intelligent agents does not depend on the user's input or specific problems that are closely related to stored knowledge. Instead, intelligent agents learn and attempt to solve the problem according to their perception of the environment and the individual goals of the agents. Applications have shown that agent based approaches have the following advantages for enterprise integration and supply chain management (Shen and Norrie, 1999):

- Increasing the responsiveness of the enterprise to the market requirements;
- Involving customers in total supply chain optimisation;

- Realising supply chain optimisation through effective resource allocation;
- Achieving dynamic optimisation of materials and inventory management;
- Realising total supply chain optimisation including all linked enterprises;
- Increasing the effectiveness of the information exchange and feedback.

3.3.5 Dissipative Structures

Chaos theory and in particular the edge of chaos metaphor, are concerned with system stability and transformation. Manufacturing organisations are continually trying to re-invent themselves and therefore are concerned with organisational effectiveness initiatives such as JIT, TQM, lean, agile and mass customisation. The idea of dissipative structures, initially developed by Prigogine (1967) in chemical systems, has been used in a complex systems framework to assist organisational change.

As reported by MacLean and MacIntosh (1998), when a system moves further from equilibrium to the point where a "descent into chaos" ensues and the system structures are broken down, then at this point, the system becomes open to its environment, importing energy and exporting entropy. This exporting of entropy is termed “dissipative”. It is used as a measure of disorder and corresponds to a new structure, operations and rules within the system. Thus the concept of "dissipative structures," proposes that as a stable system becomes chaotic, new order emerges, whilst the "edge of chaos" metaphor suggests that systems are constantly adapting and self-organising, but they do not cross the line into chaos.

Therefore, the idea of dissipative structure theory is useful for strategic managers, who are concerned with radical organisational transformation. If we consider the case of a manufacturing organisation that is continuously under-performing and is facing pressure to change, the effect of a business crisis (possible closure, a take over, receivership, etc.) will generate a chaos factor that could lead to the emergence of new order. MacLean and MacIntosh (1998) suggest a model to describe the application of dissipative structure theory to organisational change. It has three stages:

(1) *Conditioning* – comprehending the rules and structure that underpin the current organisational form

(2) *Create far from equilibrium conditions* – begin the radical and chaotic change program

(3) *Manage the feedback process* - as the new organisational form emerges create positive and negative feedback to avoid returning to the old organisational form.

The creation and management of these conditions and the resulting state of chaos often lead to an emerging order that could help organisations to move from a situation of business closure to one of business viability.

3.3.6 Genetic Algorithms

Genetic algorithms (GAs) were introduced in the United States in the 1970s by John Holland at University of Michigan. They are a powerful search algorithm based on the principles of genetic variation and natural selection (Holland, 1975). Natural operations of reproduction, crossover, and mutation are put to use onto a population of strings. A set of possible solutions can be translated as a string of binary numbers. New strings are produced every generation by the repetition of a two-step cycle. Firstly, each individual string is decoded and its ability to solve the problem is assessed and as a result assigned with a fitness value based on its performance among the population. Secondly, the fittest strings are favoured to be chosen for recombination to form the next generation. Recombination involves the selection of two strings to produce a new string that has some characteristic from both of the parents by assigning a random crossover point. In order to prevent a premature convergence to a non-optimal solution, mutation is introduced. Mutation is the small probability that any bit in a string will be flipped from its present value to its opposite (for example, 0 to 1). This can prevent certain bits becoming fixed at a specific value.

Since GAs carry out a series of searching, it is faster than conventional methods, such as gradient search methods. Furthermore, GAs work well on mixed (continuous *and* discrete), combinatorial problems. However, one has to choose the variables such as the size of population, the rate of mutation, crossover point etc with care in order to get decent results (Mitchell et al., 1991).

3.3.7 Chaos Theory

This is a collective name for dynamical systems theory or non-linear studies. Chaos theory states that the behaviour of a dynamic system is highly non-linear. In other words, it is impossible to predict exactly its outcome or future state, as the variables involved are interconnected and are reacting constantly with one another. Furthermore, this phenomenon is sensitive to the initial conditions of the system. The weather is a good example of a non-linear system as relatively small changes in the system states (pressure, temperature, etc.) can lead to relatively large changes in the weather system (tornadoes, blizzards, droughts, etc.). In 1972, Lorenz presented a paper at a conference in Washington, entitled "Does the Flap of a Butterfly's Wings in Brazil Set Off a Tornado in Texas?" to highlight the sensitivity of initial condition for such a non-linear system (Sardar et al., 1999). This metaphor is better known as the "Butterfly Effect" and acts as an emblem of chaos. Chaos theory continued to develop as scientists observed and realised that complex and chaotic behaviour could give rise to ordered structures, shapes and self-organising patterns.

Chaos theory can also be applied to the manufacturing environment. The production flow can be chaotic in a manufacturing company as the production schedule varies from day to day as a result of changing demands, customer orders etc. However, certain patterns such as total production capability and total downtime can be observed. Using computer simulation, problems such as bottlenecks can be identified and rectified. Furthermore, managers can also gain understanding about production floor activity from these simulations.

3.3.8 Edge of Chaos

The phrase *Edge of Chaos* was used by Christopher Langton of the Sante Fe Institute during his research into cellular automaton rule tables (Waldrop, 1994). Edge of Chaos (EOC) is a fluctuating zone where a slender balance between stagnation and turmoil takes place. It is a zone where life has enough stability to support itself and enough creativity to renew itself. Complex adaptive systems show this ability not to be locked into a fixed position, but also not to be disintegrated into extreme chaos.

Furze and Gale (1996) highlighted the importance of managing the tension between the two paradoxical extremes of stability and instability. Manufacturing organisations are also torn between these two contradictory stages. On one hand, they have to create new products and learn new production procedures, on the other, they have to standardise commodity and production processes. If they are stagnated, they will be too rigid to adapt to further changes. If they are too dynamic, they will not be able to cope with the resulting unpredictability and its complexity. Figure 3.5 shows a schematic representation of the edge of chaos for manufacturing organisations.

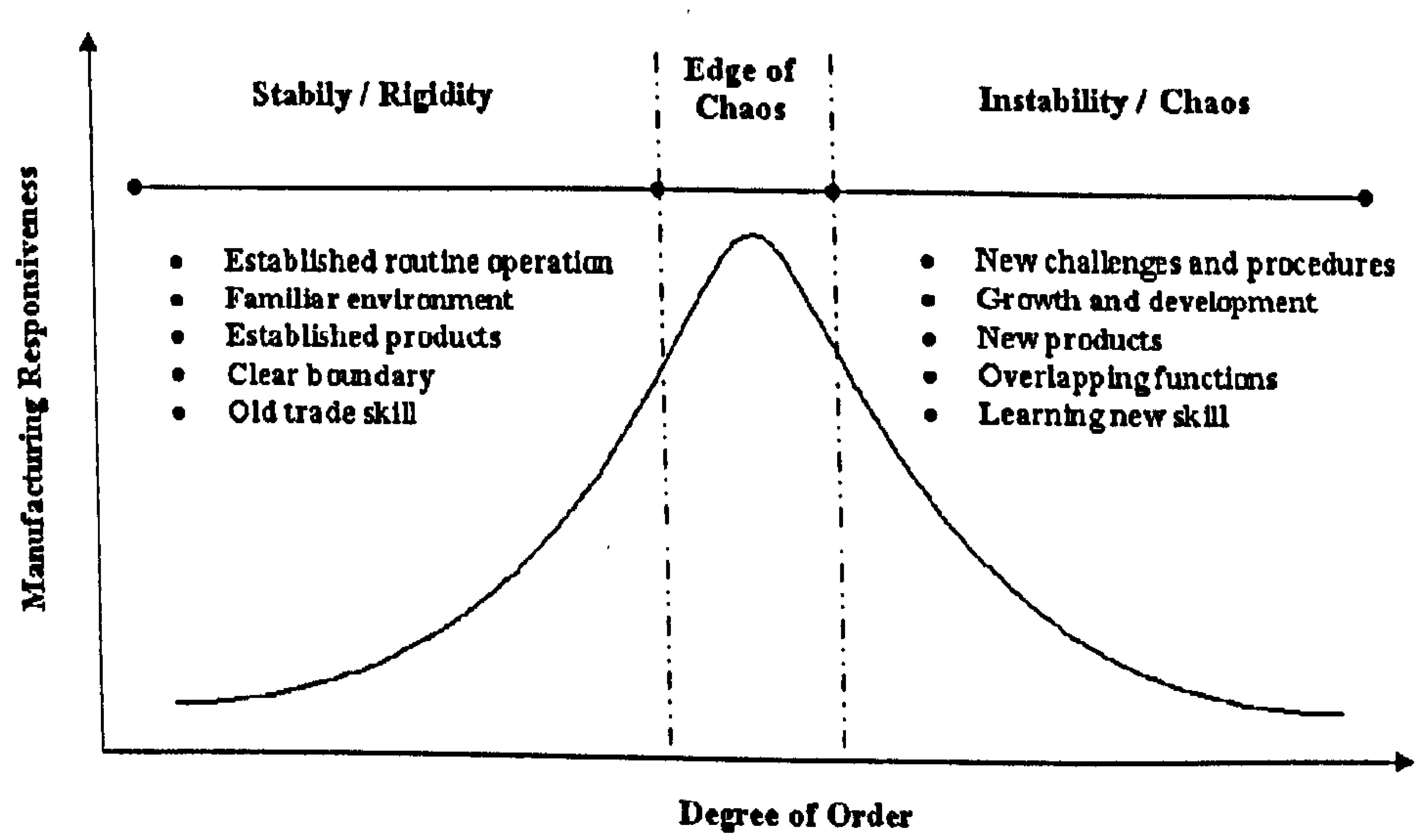


Figure 3.5 Edge of Chaos for Manufacturing Organisations

3.3.9 Fitness Landscape Theory

Fitness landscape theory is a key theory within complex systems theory. This section provides a simple introduction to the terms and concepts. They will be further developed in Chapter 4.

Kauffman (1993) used this notion to produce models that investigate the process of self-organisation and natural selection. He noted that adaptation is usually thought to be a process similar to "hill climbing" where minor variations of the species (from one generation to the next generation) result in a move towards a peak of high *fitness* on a *fitness landscape*. The concept of natural selection and survival of the fittest will push an organisation towards such peaks. This fitness landscape can be imaged as a series of hills and valleys of different heights and depths. Fitness is consider to be as the ability to successfully navigate such landscapes to survive and compete. To represent such landscapes, Kauffman created NK models, which are derived from the physics spin-glass model.

Fitness also describes the relative "success" of a species in relation to others in its environment. In other words, fitness can represent a measure of how robust a species is to adapting to its niche in the surroundings. The height portrayed by each peak on the landscape is a measure of fitness. Any movement up a hill is taken to be an increase in fitness, whilst moving downhill is a decrease in fitness.

Competition between manufacturers can be compared to walking on a fitness landscape. However, this landscape is itself not fixed and changes all the time. It is equivalent to a terrain that is made up of rubber, and is continually warping. This deforming can occur due to technologies changing, new competitors entering the market, or simply that rivals are trying to achieve fitter positions on the landscape.

3.4 Conclusion

Whilst, the issue of complexity is associated with systems that are complicated and hard to control, it is important to note that *complex systems theory* is not about the study of "complexity". It is concerned with studying the behavior of systems (often complex), to understand how critically interacting components self-organise to form potentially evolving structures with emergent properties. Therefore, a complex system is any system that has structure and exists on many scales and levels and whose behaviour cannot be reduced to one rule of description.

To summarise how the complex system theory relates to manufacturing organisations a framework is presented. The framework is shown in Figure 3.6 and has two axes: a knowledge axis which is a continuum extending between abstract and applied knowledge and a manufacturing activity axis which ranges from strategic to operational.

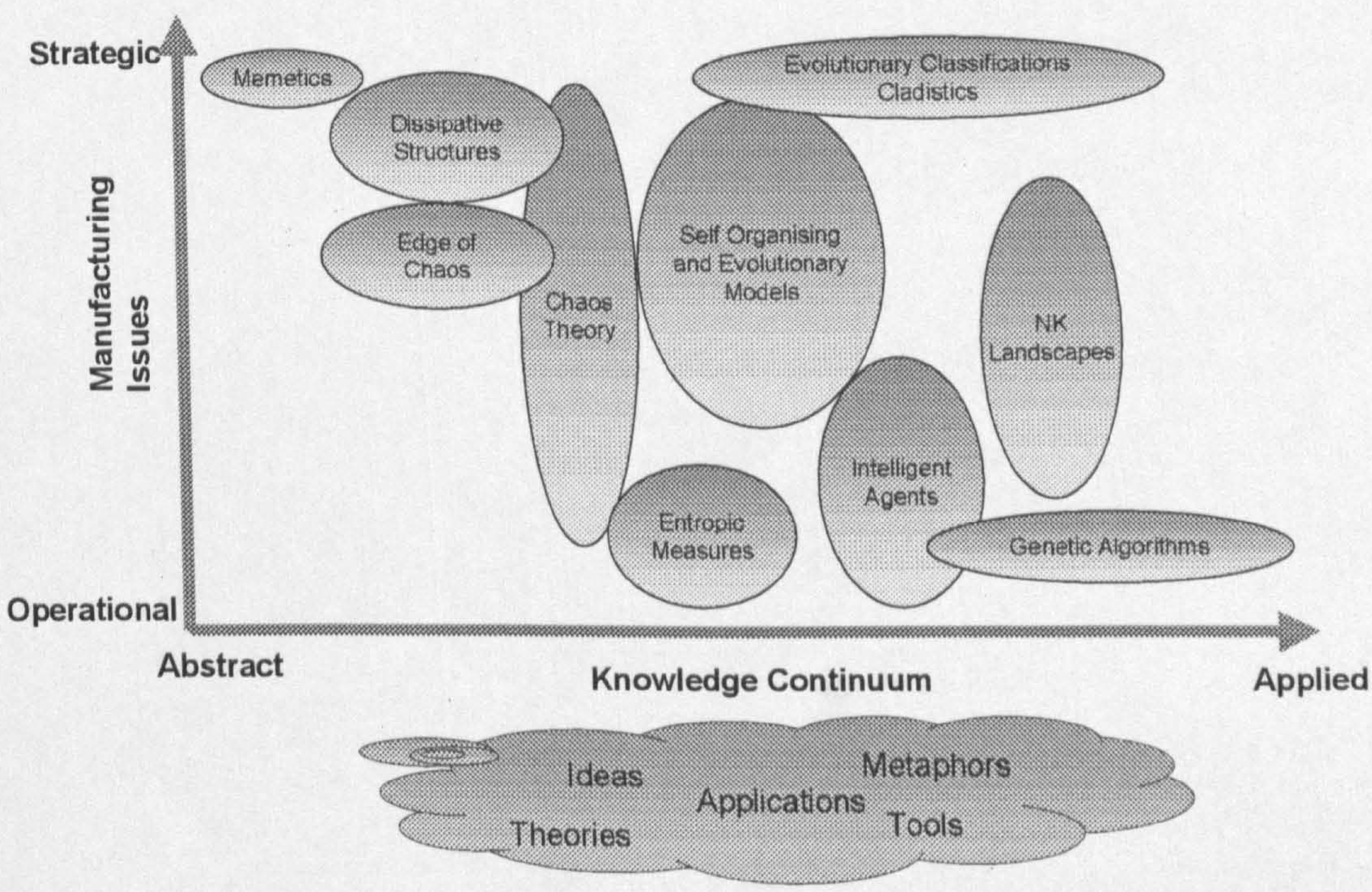


Figure 3.6 Manufacturing issues vs. knowledge continuum

This chapter, has presented manufacturing organisations as a specific type of complex system, a complex adaptive system. Such systems demonstrate goal directed adaptation i.e. they seek to satisfy their customers by continuously adapting themselves to meet the needs and expectations of the market. The industrial revolution, the quality revolution, the lean movement and the agile age are representative of such adaptive changes. In addition, complexity, in its various forms, has always existed in manufacturing and other organisations, and this is one of the main attractions of complex systems theory to the manufacturing arena.

For manufacturing organisations, complex systems theory means that they cannot be analysed and studied as a simple system, with deterministic laws about manufacturing operations and behaviour. They should be viewed as a system capable of evolving and self-organising. The value of complex systems theory is that it can provide insights on some of the most difficult and fascinating manufacturing problems around. For instance, how are manufacturing companies able to change continually in the face of global competition, how should companies design and manage production systems to cope with such change, and how do competing systems behave when having to co-exist in an environment of finite resources? To help formulate appropriate answers and strategies to these questions, this thesis will develop and apply a specific method: *fitness landscape models*.

Chapter 4. Fitness Landscape Theory

In this chapter, fitness landscape theory is discussed in detail. In order to be applicable to manufacturing management, it is explained and developed into language and idioms that managers can engage with. Glass (1996) identifies this as a potential pitfall and provides the example of non-linear theory. Non-linear theory was made accessible to business managers by researchers attempting to popularise it. This was achieved by diluting the very specialised and technical language that accompanies non-linear theory, and simplified the relevance of the theory.

The first section of this chapter provides a basic concept of how a fitness landscape may be visualised. The second section introduces the variables ("N" and "K") that are used to construct a fitness landscape model. The third section emphasises the important of co-evolution to fitness landscape models. Finally, the last section discusses the application of fitness landscape models to organisational studies and contains two sub-sections. One will discuss the potential "landscape strategies" that companies should be aware of, whilst the second discusses the similarity between fitness landscape models and organisation structure.

In summary, this chapter will:

- Discuss fitness landscape theory in detail, and
- Relate fitness landscape theory to organisations, in particular strategy formulation and organisation structure and size.

4.1 Overview of Fitness Landscape Theory

The concept of fitness landscapes is derived from nature and the notion of survival of the fittest. It has been used by biologists since the 1930s to characterise the adaptive evolution of genotypes as a search of a notional landscape of higher points (Wright, 1932). Since then it has been used in a number areas including the study of emerging technologies for generating, screening and selecting agents for drug discovery. Also, there is also a growing need to study the structure of molecular "fitness landscapes" in order to understand how to optimise search for useful molecules. This urge has led to the inception of various mathematical models to study genome evolution (for example, see Lewontin, 1974; Macken and Perelson, 1989).

One specific model that has emerged is the *NK model* (Kauffman and Weinberger, 1989; Weinberger, 1991; Kauffman, 1993). This model is itself similar to a famous and well-studied class of models which arise in an area of statistical physics, known as spin-glass theory (Stein Daniel, 1992; Weinberger and Stadler, 1993). While the physicists use these binary particle models to understand energy minimisation, Kauffman (1993) has used them to understand how organisms evolve by undertaking adaptive walks to achieve better fitness. He noted that adaptation is usually thought to be a process similar to "hill climbing" by changing minor variations of its agent (something through the next generation) towards a peak of high fitness on a fitness landscape. Natural selection, in the form of survival of the fittest, will push the population towards such peaks.

4.2 A Description of the NK Model

To help understand fitness landscapes and the NK model it is necessary to become familiar with several biological terms.

- **Gene** is a general term that expresses the hereditary physical entities that are being transmitted from parent to offspring during the reproductive process. A gene can exist in different forms or states.
- **Alleles** are the alternative forms of a gene and the combination of alleles present in an organism determines what the organism will be like with respect to the character controlled by the gene.
- **Genome** is the string of gene. The position of a gene along a genome is called **locus** (plural: **loci**) of the gene. Figure 4.1 shows the relationship between the terms introduced so far.

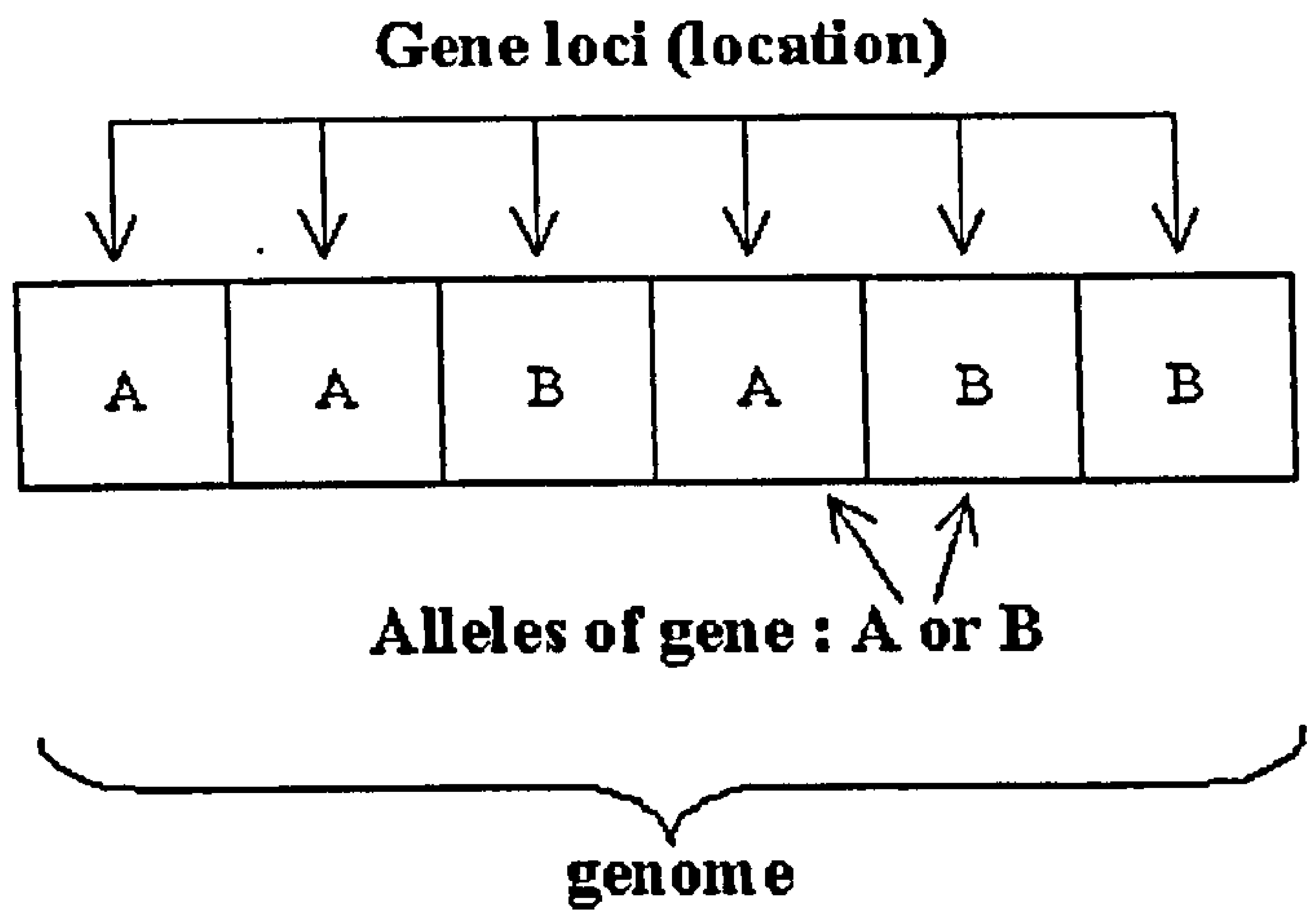


Figure 4.1 Genetic Terminology

- **Genotypes** are the whole set of genes present in an organism. The physical or biochemical expression of the genotype is called the **phenotype**. The difference between a genotype and phenotype is that the latter can often be directly determined by inspection, whilst the former can be determined only from studying the organism's desoxyribose nucleic acid or commonly known as DNA. Therefore, all organisms having the same phenotype do not necessarily have identical genotypes.

The biologists' view of the world is that the organisms evolve over time to survive. Within this cognition, adapting organisms face conflicting constraints in their internal structure as well as in their interactions with the environment. The genotype determines the hereditary potentials and limitations of an individual from embryonic formation through adulthood. It will have a affiliated fitness value, expressed as the likelihood of survival in its environment. For several decades, biologists have pictured a biological landscape where organisms adapt to and search this space of genotypes for fitness peaks on rugged, multi-peaked, mountainous "fitness landscape". The conflicting constraints faced by the organism imply that it is not possible to search for the optimal genotype, but there are many locally optimal compromise genotypes that exist in the large space of possibility. Therefore in a wider sense, genotypes can be viewed as a representation of a feasible "solution" in a problem setting that has many compromise solutions.

Hence, a fitness landscapes model consists of three parts: *a sequence space*, *a fitness function*, and a *neighbourhood relation*. Sequence space (S), is an abstract representation of the collection of all objects of interest (for example, proteins, RNA molecules, genome, firm, organisation strategy, etc.) as a sequence of elements chosen from an appropriate alphabet. Thus, an organisation with strategy (N) may be represented by a point in the sequence space consisting of the set of all possible organisation strategies of length N. A genome can contain loci with wide variations in the number of alleles, while a typical amino acid can have up to 20 possible proteins and a nucleotide can have 4 possible polynucleotides. Therefore, for an amino acid of N loci, there are 20^N possible proteins and likewise for a nucleotide, it is 4^N. To simplify the simulation, Kauffman assigned haploid genomes with two alleles at each locus for his NK model. In other words, the simplest form of the NK model has two alleles at each locus. In this case, a genome is represented mathematically as a binary N-vector, $\mathbf{x} = (x_1, x_2 ... x_N)$, in which $x_i = 1$ means that one of the two alleles is present at locus i and $x_i = 0$ means that the other allele is present at that locus. Geometrically, each of the 2^N binary N-vectors is a corner point of an N-dimensional unit cube.

Next the *fitness function* is introduced. A fitness function, $f(\mathbf{x})$, assigns a real value "fitness", between 0 and 1, to each genotype, $\mathbf{x}$ in the sequence space, S. A fitness function may reflect, for example the efficiency of an organisation in marketing a new product or the effectiveness in dealing with customers' complaints. A value close to 0 indicates poor fitness whilst a value close to 1 indicates good fitness. In principle, fitness values can then be plotted as heights on a landscape of multidimensional sequence space, i.e. a series of hills and valleys. The hills represent high fitness and the valleys represent low fitness. In Kauffman's model, the fitness $f(\mathbf{x})$, is the average of the fitness contributions, $f_i(\mathbf{x})$, from each locus i, and is written as:

$$\mathbf{f}(\mathbf{x}) = \frac{1}{N}\sum_{i=1}^{N} \mathbf{f}_i(\mathbf{x}) \qquad \textbf{Equation 4.1}$$

Using a simple manufacturing example such as purchasing a piece of equipment for a specific job, there are many types of machines that could be purchased and this set of alternatives is known as S. For simplicity, only the following resources are considered: Machine A, Machine B and Machine C and therefore N=3. There are two values for each alternative: to buy the machine (1) or not to buy the machine (0) and therefore A = 2. This simple example provides a straightforward binary code of the problem, with the total combination of solutions being $A^N = 2^3$ (i.e. 8 possible solutions). However, there is no limitation that the value has to be binary, for instance the options could include: buying a brand new machine, renting the machine, buying a second-hand machine, and not buying the machine. In this case, the possible *alleles* for each locus will be 4, and the total number of solutions will be 4^3 (64 possible combinations).

With each solution, a value (from 0 to 1) - the *fitness*, can be allocated. The definition of *fitness* is an important part of the modelling. It could be defined in relation to the profit returns (the cost of the machines, worker overheads, etc.) for each combination of machines, or be relative to the increase in the number of components that the company could produce. In this example, random fitness values were allocated and thus, the total possible number of combinations and the assigned fitness values for each individual combination is shown in Table 4.1.

	Machine A	Machine B	Machine C	Assigned Fitness
000	✗	✗	✗	0.0
001	✗	✗	✓	0.1
010	✗	✓	✗	0.3
011	✗	✓	✓	0.5
100	✓	✗	✗	0.4
101	✓	✗	✓	0.7
110	✓	✓	✗	0.8
111	✓	✓	✓	0.6

Table 4.1 Table of combination of machines and the related fitness.

As N=3, a three-dimensional cube can be used to represent the possible combinations and their relationship to each other (see Figure 4.2). Each corner point of the cube represents a solution and its fitness value. The distance from each solution to its neighbouring solutions is termed the *Hamming distance*. A solution *A* is said to be a *neighbour* of solution *B* when there is only one different allele in a gene among the two solutions. For example, 000 will be a neighbour to 001, 010 and 100, all of which is just one Hamming distance away from it.

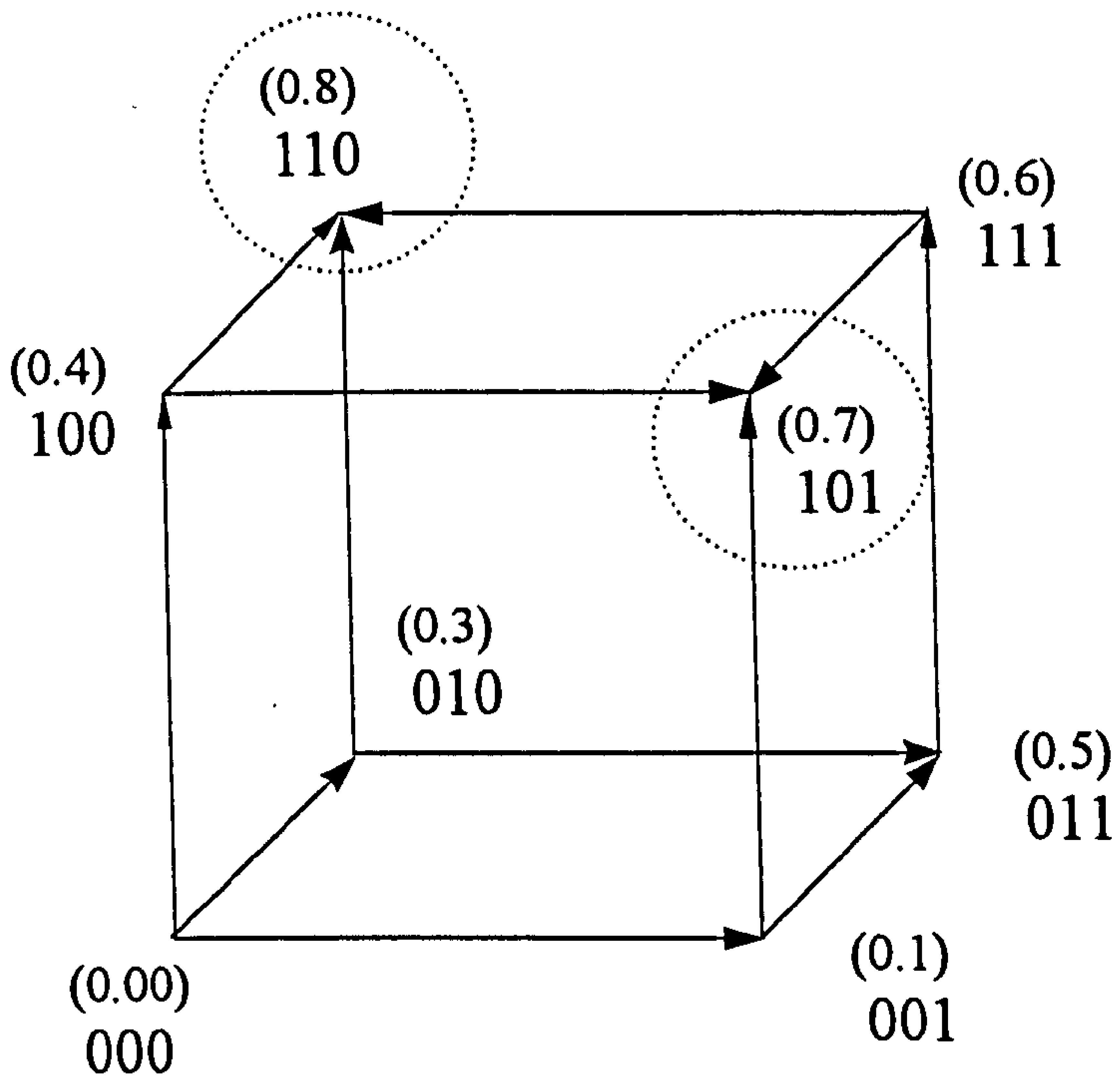


Figure 4.2 Cube on Fitness of machine.

To visualise the hypercube when N increases (i.e. to four dimensions) this would requires a four-dimensional cube. Fortunately, the essential features of these landscapes can also be captured and reflected in the much simpler geometry of Boolean hypercubes as shown in Figure 4.3.

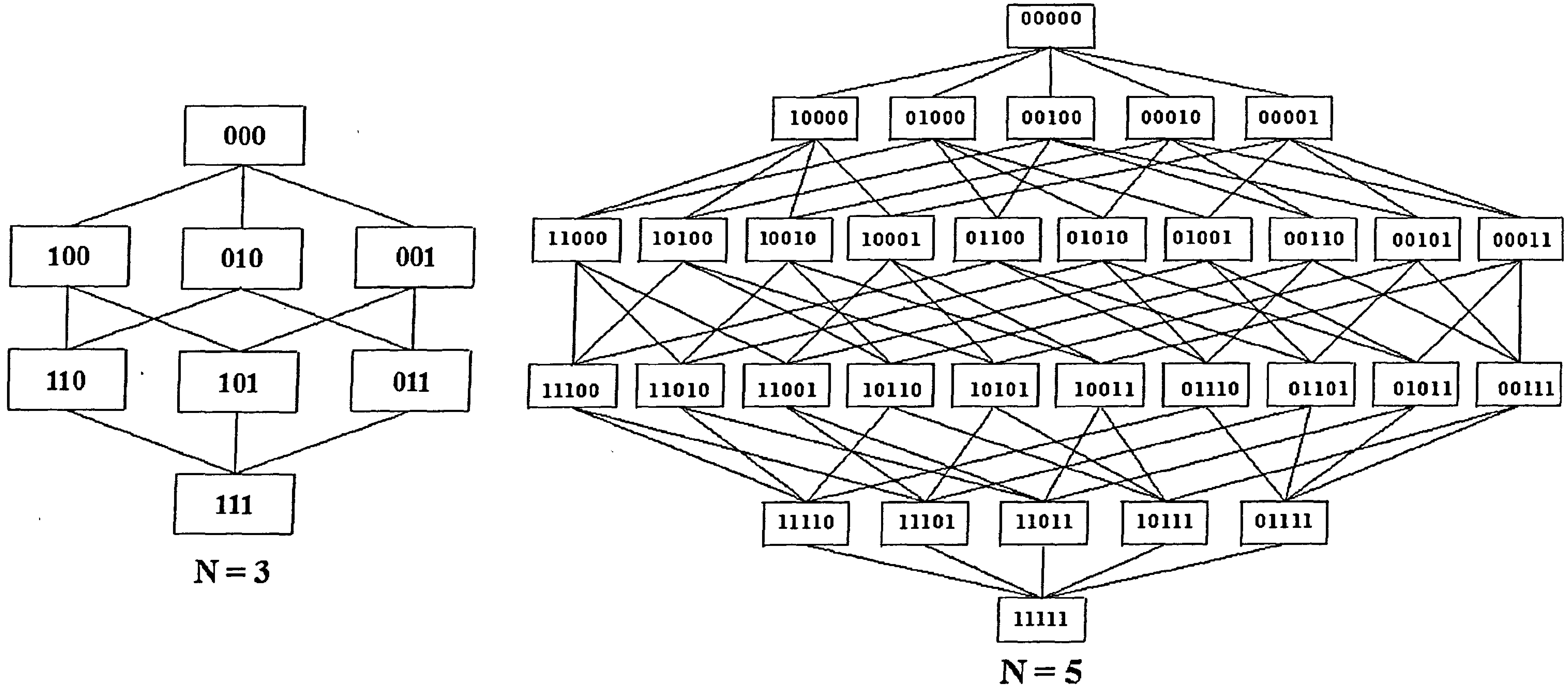


Figure 4.3 Boolean hypercubes for binary sequences of length N=3 and N = 5

Finally, the third part the concept of the adaptive walk is introduced. Evolution is assumed to be a process of moving from one genome to another in search of an improved fitness. This is achieved through gradient descent, recombination, genetic algorithms, etc. In Kauffman's model, the *one-mutant neighbour* method is used. To describe this method we must refer to Figure 4.2. If we randomly choose any point (e.g. point 011) there are three possible *one-mutation neighbours* (points 010, 111 and 001). If the point 001 has a fitter neighbour (i.e. a higher fitness value) then the organism, through evolution will evolve from the inferior point to the fitter point. The arrows on the lines of the cube represent either an uphill or downhill walk. A *local peak* is a point from which there is no fitter point to move to in its immediate neighbourhood, such as point "101". A *global peak* is the fittest point in the entire landscape, i.e. point "110".

Referring back to the example about purchasing machines, several features can be highlighted. Firstly, a company with no machines will know the benefit or fitness to be gained by purchasing a machine as specified by the fitness map. Companies can evaluate such fitness measures along with other considerations such as finance, factory size, etc. The landscape provides a starting point for the company to navigate with confidence through the uncertainty to the global point. Secondly, if a company already possesses a machine and exists within the landscape, then knowledge of the landscape will help guide/navigate the company towards the global point by suggesting the best buy/sell policy of equipment. This simple fitness landscape will show whether a company is on the right track to the global point, although they might suffer a temporary loss in fitness in travelling towards the final destination. For example, a company that has Machines A and C is at a local optimal point in the landscape, and by selling or buying another machine, the result is a decrease in fitness. However, to achieve the global optimal point in the landscape, the company has to sell Machine C and purchase Machine B. Therefore, if a company is stuck at a local optimum, in order to reach the global peak, it has to go downhill and before it can climb up again.

4.2.1 The K-factor

In order to control the amount of *epistatic* interaction at each locus *i*, Kauffman (1993) introduces an integer parameter, K. The term *epistatic* refers to the interactions or dependency between the different genes or elements in the solution. In other words, K represents the connectivity for the problem. Hence, in the case of K=0, this indicates no interaction. The other extreme that indicates the maximum complexity, K = N-1 indicates interaction with all the other loci in the genome. In the spin glass model from physics, this term is know as "frustration", because it can lead to many local fitness maxima. Using the machine example, the K factor is 2, as the presence or absence of each machine affects the fitness of the other two. The NK model assumes that the contribution of each locus *i* to the overall fitness of the genome, depends on the allele at locus *i* as well as on the alleles at K other loci. There are 2^{k+1} possible combinations for the alleles at these K + 1 loci, so there are 2^{k+1} possible fitness contributions for each locus. Thus, the value of $f_i(\mathbf{x})$ is the number that corresponds to the combination of alleles at locus *i* and the K loci that affect locus *i*.

4.3 Construction of a NK Fitness Landscape

The mapping that is shown in Figure 4.2 is a conceptual one, but it is extremely difficult to build a formal landscape model of manufacturing organisations using empirical data. A precise landscape is hard to construct, due to the problems of defining a fitness value for manufacturing organisations. To date there has been insufficient research to associate fitness to different organisation types or strategies.

A good starting point is the study by Weinberger and Stadler, who examined the free energies of ribonucleic acid (RNA) secondary structure folding. RNA is a generic term that contains the genetic information in some viruses or lower form of organisms. They noted that the measurement of every free energy on the landscape is not and cannot be all measured as this would require an almost infinity number of measurements. Even if such detailed information were available, it would not be beneficial to researchers, because the subject of interest is the global effects and not the local properties. To capture the fundamental concept of fitness, it is useful to generalise the notion of random landscape (Weinberger and Stadler, 1993). Therefore, by assigning fitness values randomly to the every possible space, a random landscape can be formed (Kauffman, 1993).

Table 4.2 shows an example of how fitness values are assigned to a random landscape.

Representation of the N-K model for N=7, K=2, adjacent neighbourhoods. The tables show the computing the forth and fifth site fitness.

Computing the contribution of The fourth bit position				Computing the contribution of The fifth bit position			
Bit 3	Bit 4	Bit 5	Random Fitness Value	Bit 4	Bit 5	Bit 6	Random Fitness Value
0	0	0	0.73	0	0	0	0.86
0	0	1	0.15	0	0	1	0.11
0	1	0	0.23	0	1	0	0.36
0	1	1	0.58	0	1	1	0.07
1	0	0	0.72	1	0	0	0.2
1	0	1	0.58	1	0	1	0.16
1	1	0	0.27	1	1	0	0.51
1	1	1	0.19	1	1	1	0.57

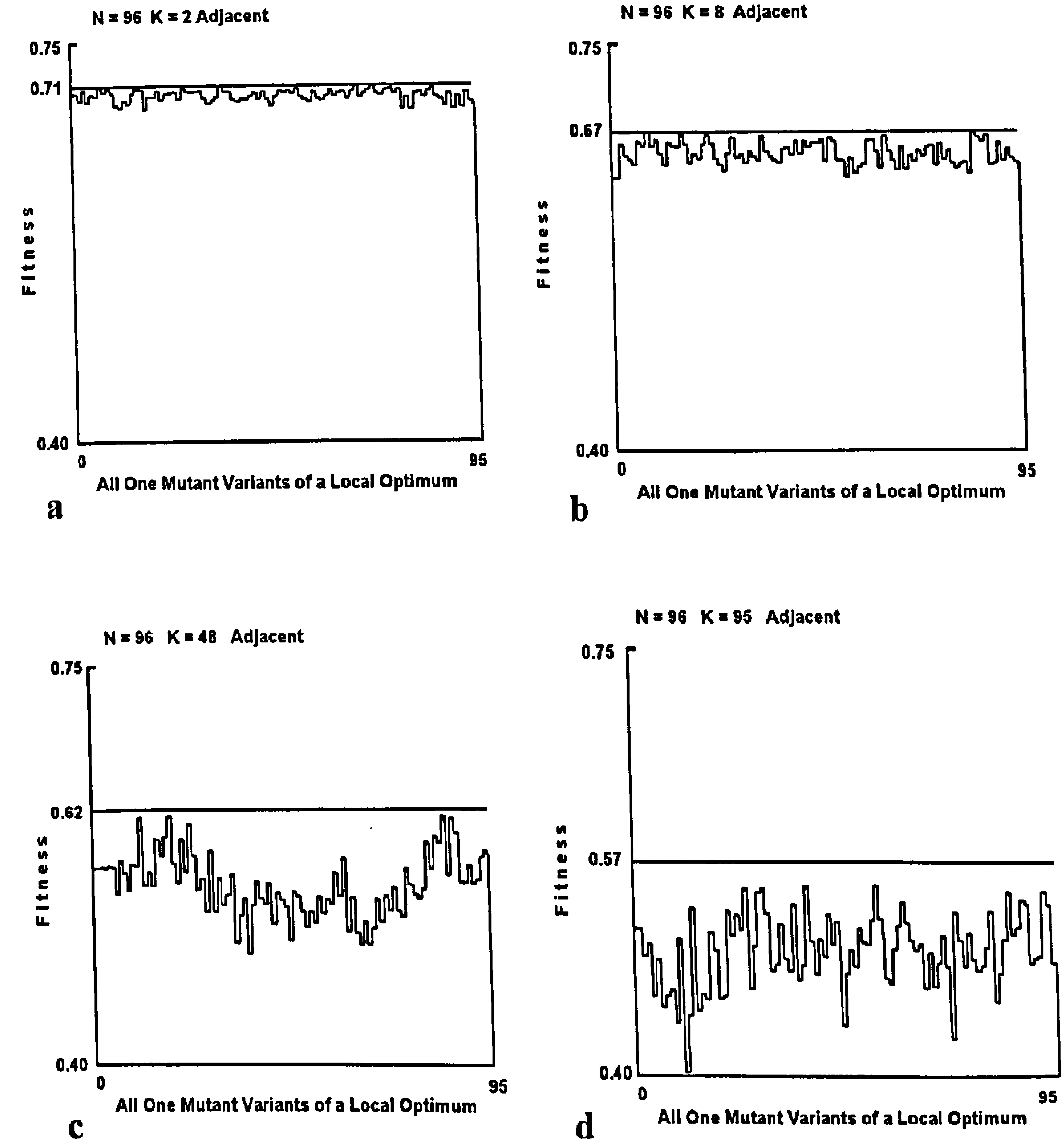
In the 7-bit string whose fitness is to be computed, the sub-string consists of bits 3, 4 and 5 is "001", so the forth site fitness is 0.15. Similarly, the sub-string consisting of bits 4, 5 and 6 is "010", so the fifth site fitness is 0.36.

Bit position	1	2	3	4	5	6	7
N bit string to be assigned a fitness	1	1	0	0	1	0	1
Fitness contribution of bit position	0.45	0.85	0.24	0.15	0.36	0.55	0.19

Fitness of above string = average of fitness contributions = 0.399

Table 4.2 example of how fitness values are assigned.

Given the values for N, K, and the N tables of 2^{k+1} uniform 0-1 random numbers, the collection of all 2^N binary vectors, together with their fitness, is defined by **Equation 4.1** which constitutes the NK model. With these features, the NK model created by Kauffman is a statistical model of molecular fitness landscapes, that could be used as a test-bed for examining optimisation strategies in molecular search. Furthermore, Kauffman (1993) explored this model by creating several simulations involving the manipulation of the K factor with a fixed N factor (see Figure 4.4). Also, several other researchers carried out work to develop this NK model (Perelson and Macken, 1995; Solow et al., 1999).



Source: Kauffman (1993), pg. 59

Figure 4.4 The ruggedness of NK landscape

The graphs produced by Kauffman (Figure 4.4) show that when the value of K is small, the peak of this resultant landscape can be quite high. Also, when the value of K increases, the peak decreases and the terrain of the landscape becomes more unrelated (mountainous).

4.3.1 The K-factor

K = 0 yields a smooth, correlated, single-peaked landscape

If each gene's fitness contribution to the whole genome is independent of all the others genes, in other words there are no epistatic interactions among the N genes, then the resultant landscape is relatively simple, smooth and highly correlated. The neighbouring genomes in a smooth landscape have similar fitness values. When one gene changes, the fitness contributions of the other genes remain the same, therefore the one-gene changes do not greatly influence the other fitness values by more than 1/N. The larger N becomes, the smoother or more highly correlated is the resulting landscape. Such fitness landscapes have a single global optimal genome, with all the other genomes being sub-optimal. For each gene locus, one of the possible alleles, will have a higher fitness contribution. Therefore, the global optimal type encodes all higher fitness values for each gene. Any sub-optimal genomes can be changed to the optimal genome by switching each low-fitness-gene to the corresponding higher-fitness ones. Consequently, for this landscape the optimal genome can be reached by following upward steps only. The resultant landscape will have a similar profile to that of Mount Fuji. Figure 4.5 shows a landscape for K = 0.

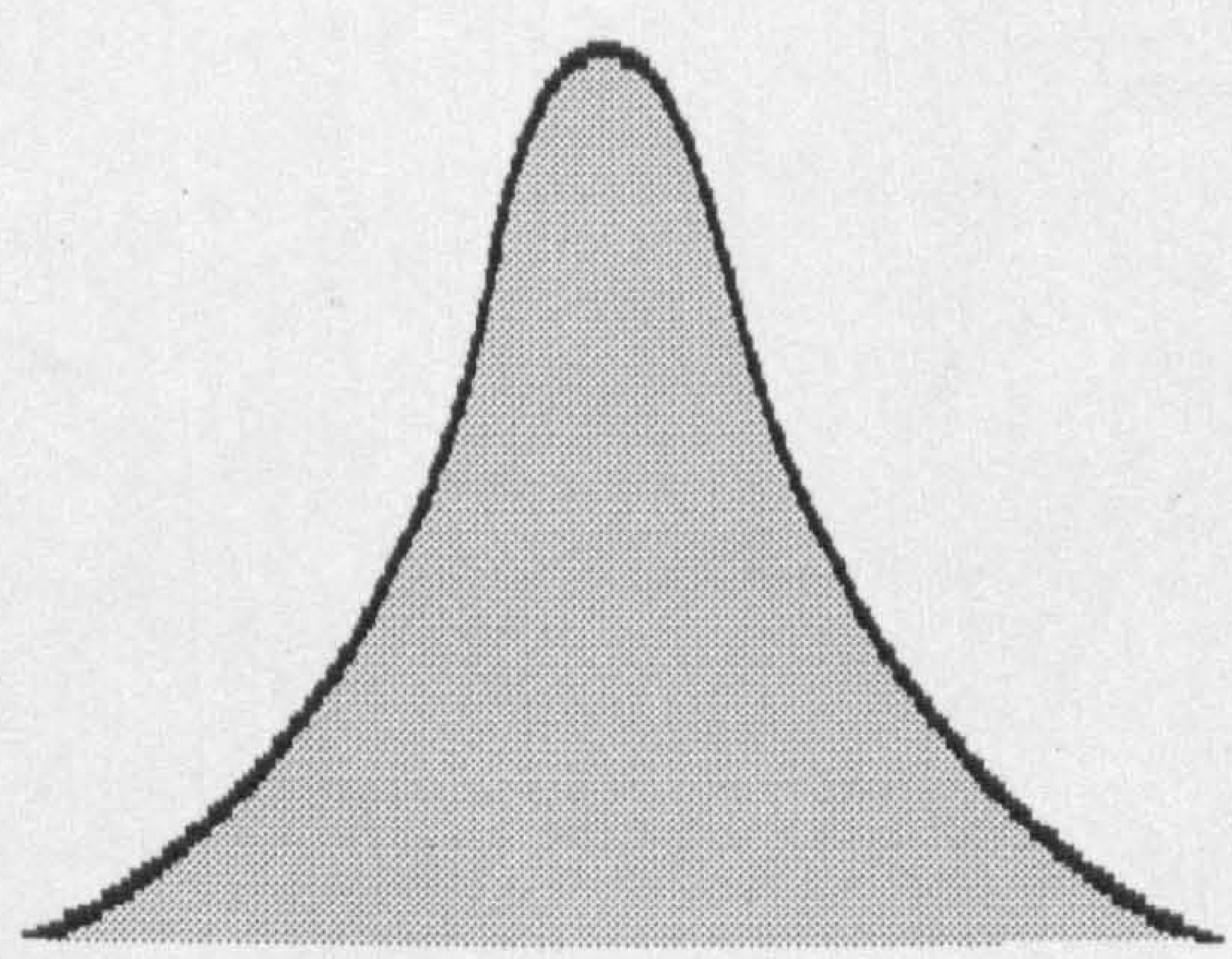


Figure 4.5 Fitness Landscape for K = 0

In terms of the machine example that was presented in Section 4.2, a K = 0 would imply that each machine has an optimal value, either 0 or 1, that is independent from the values given to the other machines. Therefore the global optimal would simply be the optimal configuration of all the three machines, i.e. the landscape for this problem would only have one optimal peak. Such landscapes mean that each step towards the global optimal is always uphill. This is because each machine can be maximised without causing any conflict or damping the fitness of another machine.

K=N-1 yields a rugged, uncorrelated, multi-peaked landscape

As the connectivity value, K increases from 0 toward its maximum value of N-1, the fitness landscape changes from a smooth, correlated, single peak optimum to an increasingly rugged, uncorrelated, and most importantly multi-peaked landscape. This is similar to the "random energy model" (Derrida, 1981). The difference between these two landscapes is that the K=N-1 landscapes show some correlation between neighbouring points, whilst the random energy model is totally random and unrealistic for most practical situations. The reason for multi-peaks is that by increasing the number of epistatic interactions, there is an increase in the conflicting constraints within the system and the height of the peaks are lower. Therefore, the landscape does not clearly reveal the global optimal, because there are many local peaks and valleys producing a profile similar to the Alpine Dolomites. Figure 4.6 shows a landscape for K = N - 1. For organisations, the consequence is that they can reach a local peak relatively easily, but that it may have a value which is much less than the global peak.

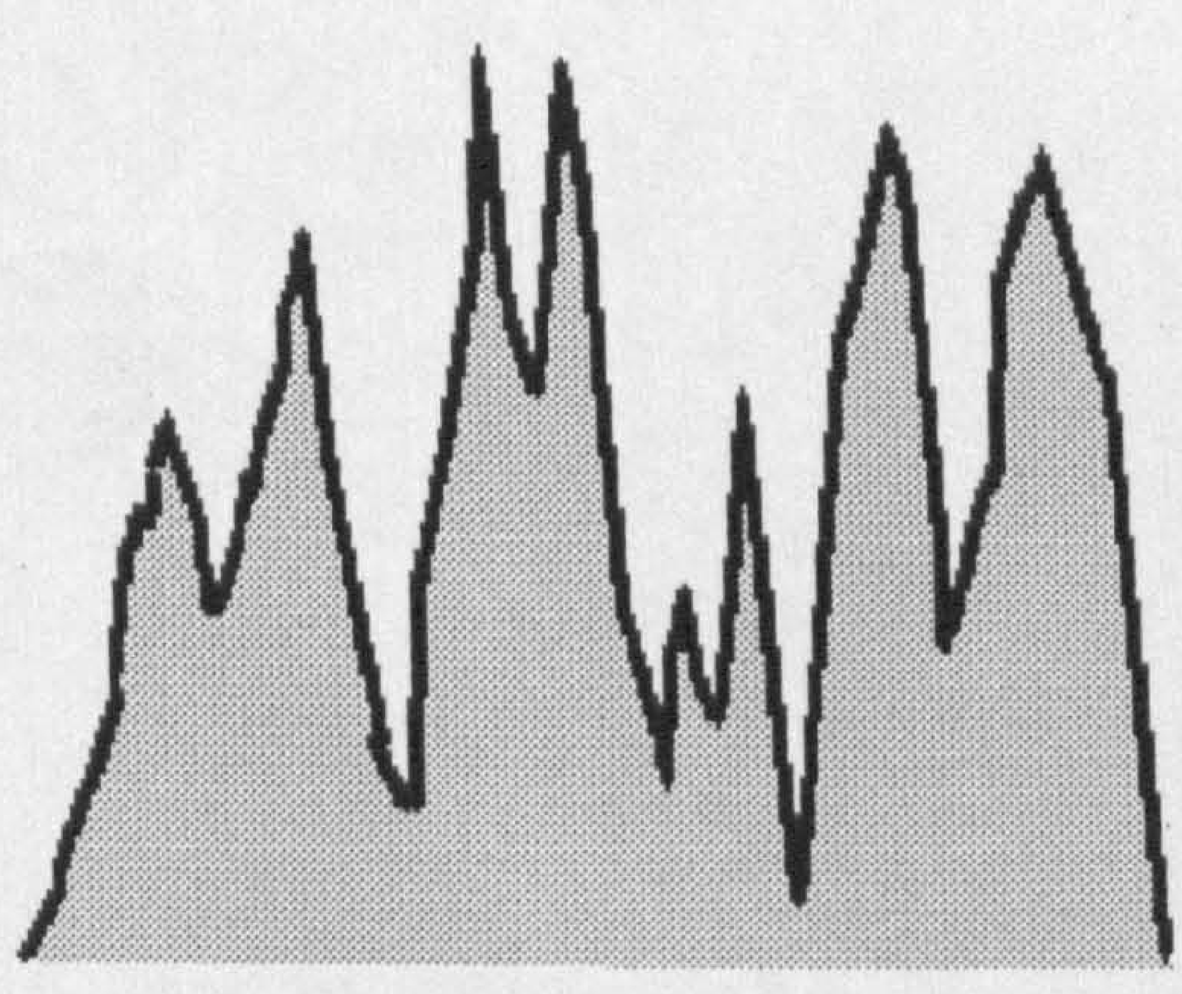
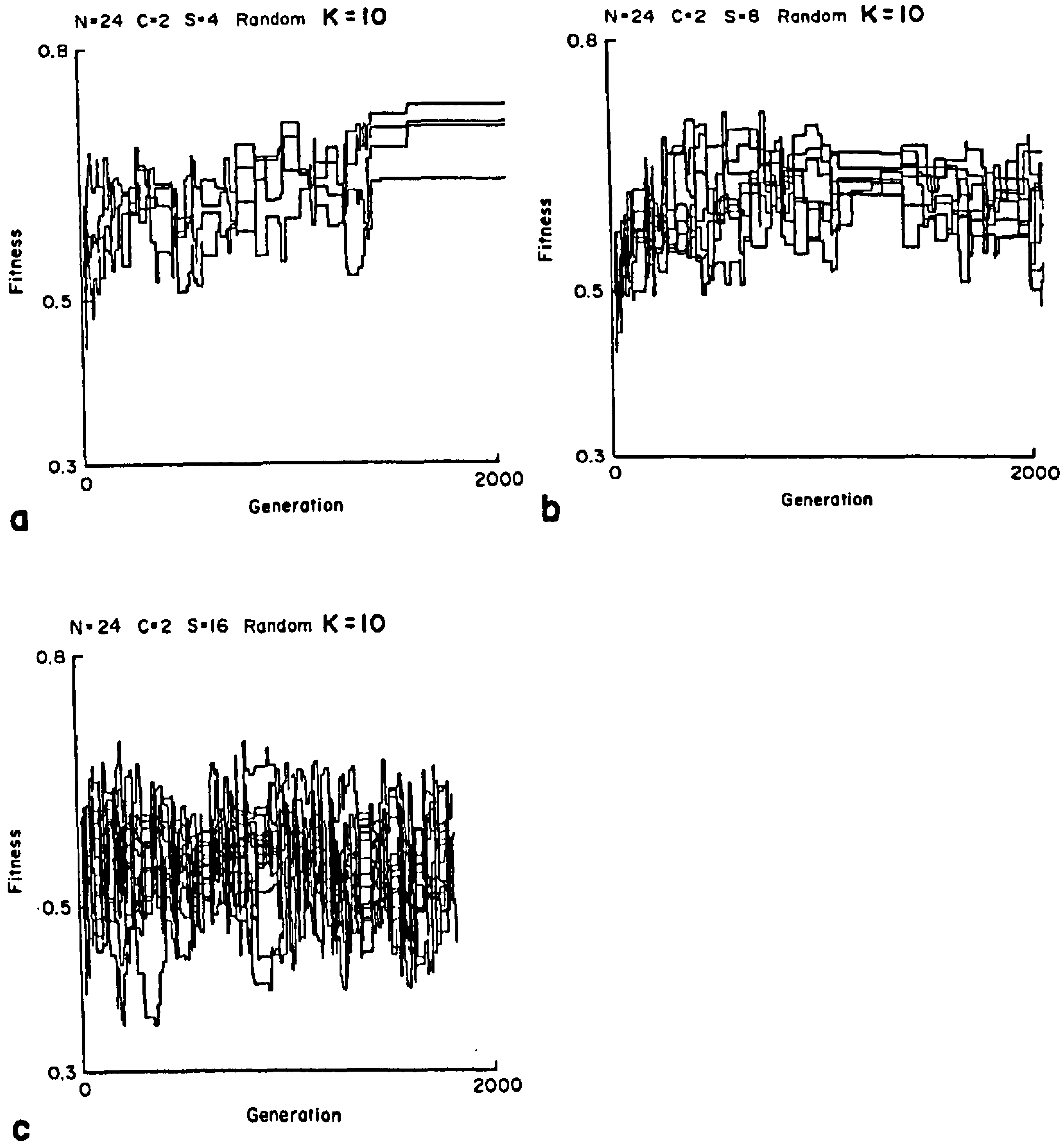


Figure 4.6 Fitness Landscape for K = N - 1

4.3.2 The C-factor

Kauffman's NK model is considered to be a fixed structure, i.e. the string N is not influenced by factors outside of its system boundary. In other words, it is a static environment and the model in the landscape does not interact with its surrounding. In practice this is considered to be impossible. Therefore, Kauffman introduced a C-factor, which provides the concept of *coupledness*. Coupledness means that systems will not just depend on internal factors, but also depend on the outside system. For example, the fitness of an insect (e.g. a fly) will depend on the fitness of its predators, e.g. a frog. If the frog is continually evolving to have a long and sticky tongue, then the chances of the fly of escaping are fading. This will in turn decrease the fitness of the fly. In a business context, if the fitness of one company is increased, it is almost certain to affect the fitness of other companies. Figure 4.7 shows the result of a computer simulation that simulates the fitness of species that affected by coupledness. The species are not able to settle into an equilibrium state, because they heavily coupled with the outside system (See Figure 4.7 b and c). This coupledness triggers an effect known as the *Red Queen Effect.*



Source: Kauffman (1993), pg. 254

Figure 4.7 The coupledness of NK landscape

4.4 The Red Queen Effect - An Adaptive Process

The discussion up to Section 4.3.1 has revolved around a fixed fitness landscape. Even in the case of a single population, this is a drastic oversimplification. Models with a fixed fitness landscape describe a situation where there is no interaction between individuals (except when there are limited resources). They are unable to describe a situation where more than one species is present. Section 4.3.2 has briefly tackled with this issue. As with the frog-fly example, there will be interaction between species in any environment, and this could lead to three possible situations: *competition*, *exploitation*, and *mutualism*. *Competition* refers to the presence of species that hinder the population growth or fitness of others. *Exploitation* is when species A stimulates the growth of species B, while the presence of species B inhibits the growth of species A. *Mutualism* refers to the situation where the presence of each species stimulates the growth of the other, for example, the relationship between PC companies and software developers.

Co-evolution is a process where the adaptive moves of each entity change the landscapes of its neighbours in the environment (e.g. ecology, industry or technology economy). In other words, no one species or system will be able to isolate itself within its boundary and not be affected by the outside environment. This is known as the *Red Queen Effect*, named after the character, Queen of Hearts in Lewis Carroll's, "Through the Looking Glass". In this book the character Alice whilst trying to escape the Queen of Hearts has to keep on running just to stay in the same place. This situation applies to all species that have to keep moving in a never-ending race just to sustain their current level or position in the system. This term was originally used by Van Valen (1973) in his discussion of speciation and extinction, and later used by Kauffman (1993) to explain the effect of co-evolution. In evolutionary language, this metaphor means that the evolutionary changes are mainly directed to avoid extinction in an ever declining environment, rather than to improve the fitness in a stable environment. Each of the S species performs an adaptive walk in its own genome space, where the fitness landscape depends on the state of the other species. After a transient time the fitness values of all the species reach a metastable state where the mutation of a species would lower its own fitness. There is no global function being optimised. Every species has reached a point which is a local optimum provided that the other species do not mutate. In economic theory, this state is known as *Nash equilibrium* (Kauffman, 1993; Fernandez and Bierman, 1998).

It can be difficult to see the Red Queen Effect in organisations, as the advantage evolved by this approach will be neutralised by the other competitors. As a result, measurements such as market share, growth, profit, etc. might lead to a belief that such an effect does not exist at all. However, as we view consumer products, we find unquestionably that the general quality of products has increased collectively over the years.

4.4.1 Consequence of the Red Queen Effect

The Red Queen Effect is a situation that is a familiar to most businesses. Once a move that yields a cost advantage is developed, it is not long before another competitor creates something similar or better. A new market created by a company will find that it soon becomes flooded by competitors and thus most competitive advantages are short-lived. However Barnett and Hansen (1996) suggest that an organisation exposed to competition is likely to learn as a result. Without the Red Queen Effect, a species may stop evolving for better adaptation. It may be able to survive for the time being, but it is highly likely that it would face extinction once stronger competitors emerge or its environment changes. This is one of the reasons given to explain the demise of British Motorcycle industry, when Japanese counterparts entered the market (Smith, 1981). Therefore the Red Queen Effect can result in important long-term developments even though the changes are themselves very small. It is these small changes that trigger the species towards a bigger evolution.

4.5 The Application of Fitness Landscape Theory to Organisations

The following sections discuss how the various terminology in fitness landscape theory can be related to organisational studies. Special emphasis is placed on organisation size and organisation structures (U-form and M-form). These two factors affect the way organisations adapted to increase their survival. As organisations grow in size and complexity, more focus are needed for the organisation to run effectively.

4.5.1 Organisational Size and Structure

This section discusses the K factor that can be found in organisations in term of size and organisation structure.

4.5.1.1 Size of Organisation

The question of "how large a multi-level unit of hierarchical organisation can be and still have effective managerial leadership?" is a common and important issue for organisational researchers. In the 1920s, the management expert Graicunas, suggested a rule of thumb that managers should have between three to six subordinates in order to have effective span of control (Nickle, 2000). However, Clement and Jaques (1991) rejected this as a theory and suggested that this "rule of thumb" approach created too many levels of organisation and that its only merit point is that it is a system that facilitates easy pay and grading. To counter this rule of thumb, Clement and Jaques suggested that an operational manager could cope with up to 70 immediate subordinates, and that a middle manager who has to spend more time in meetings and conferences, could manage 10 to 20 immediate subordinates. However, Clement and Jaques suggested that in order to achieve the maximum number and still maintain a good span of control, certain conditions have to be fulfilled. One of these conditions is that managers have to spend time overseeing subordinates and spend less time at meetings, or dealing with scheduling or technical problems. This means that the span of control decreases as the variability of the conditions and the absence of the manager increases. Clement and Jaques deduced this rule based on 40 years of developed principals and practical experience. However, they also forewarned that the top limit number suggested, could be reduced by other factors such as technology and control processes. Table 4.3 shows the suggested level and the number of employees as developed by Clement and Jaques (1991).

Level	Number of employee
II	Less than 70
III	250-300
IV	2,000
V	6,000
VI	30,000
VII	100,000
VIII	1,000,000

Table 4.3 Level and Number of employee.

4.5.1.2 Unitary Form Enterprise (U-form)

In the 1800s, companies with mainly single products such as steel, tobacco, oil, etc. tended to be the largest organisations. Because of multi-functional tasks, these companies were organised according to business function, i.e. the type of business activity they were involved in. With this structure a company could have

1) A finance department
2) A marketing department
3) A personnel department
4) A production department
5) A research department

This arrangement is known as unitary form (or U-form) (Williamson, 1975). Figure 4.8 shows an organisation chart of a U-form organisation.

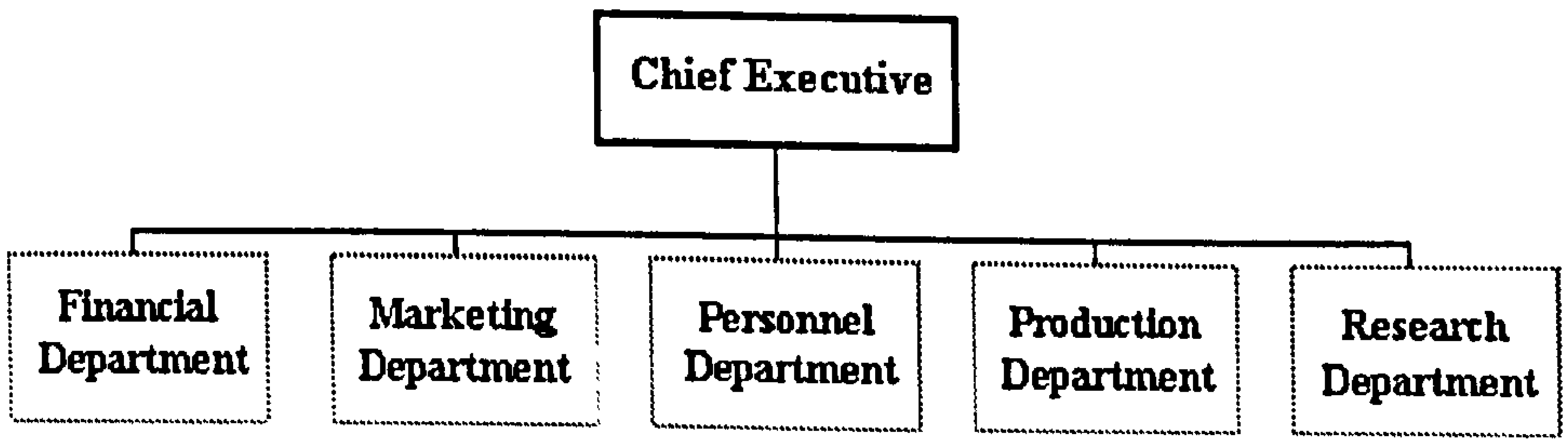


Figure 4.8 Unitary Form Organisation Structure

Through functional specialisation, a company could harvest economies of scale and an efficient division of labour. However, there must be a pre-condition that senior managers have appropriate control over the various parts. Therefore specialisation by function is often found in moderate sized organisations where complexity is still relatively manageable.

However, as an organisation expands either in size, product volume, geographical spread, etc. complexity increases. As complexity increases, senior management will suffer from a loss of control through a weakened command chain. Furthermore, the administrative role of senior executives increases to an extent that the entrepreneurial responsibilities cannot be carried out efficiently. The process of co-ordinating and monitoring, which is the corner stone of the U-form organisation, becomes a stumbling block as the organisation grows. The complex tasks begin to overload the small number of senior managers. This overload in the long run will affect the strategy and direction of the organisation, and in the short term, the efficient running of company in its operational tasks.

The task of dealing with the function and operation of the organisation, results in senior managers focusing on sub-goals as the long term direction becomes drowned by everyday operational tasks. As a result, the task of identification and formulation business strategy for an organisation may be sacrificed as the managers spend their time dealing with the functional parts of the organisation. One could install or add more hierarchical levels in order to tackle this defect, but as the hierarchical levels increase this produces another problem - the loss of information during transmission between hierarchical levels. As information such production schedules are transmitted through the hierarchy, it often becomes summarised and in some case misinterpreted.

4.5.1.3 Multidivisional Form Enterprise (M-form)

As discussed above, as the complexity of U-form organisations grow, internal operating problems begin to surface. Taking a historical approach and using companies such as General Motors, Standard Oil of New Jersey (later know as Exxon), Sears Roebuck and the DuPont company, Chandler (1962) monitored how the diversification strategy of these four companies stretched and strained the functional structure that these companies had in place back in the 1920s. He also observed that these four companies, independently developed a similar organisational structure to tackle the problem. Chandler used these case studies to compare and analyse the development of the new structure. For example, in General Motors, the management classified its products into different price categories as the market emerged through the years. With increased difficulties in monitoring performance and deploying marketing decisions for the different segments, the company then re-structured so that performance in different segments became the responsibility of divisional managers. For monitoring and control purposes, performance measurements such as return-on-investment were introduced. These companies replaced the functional divisions of the U-form structure with a quasi-autonomous operating division. These divisions were organised mainly along product, brand or geographic divisions. Chandler named this organisational form - *multidivisional structure* (M-form). An example can be seen in Figure 4.9.

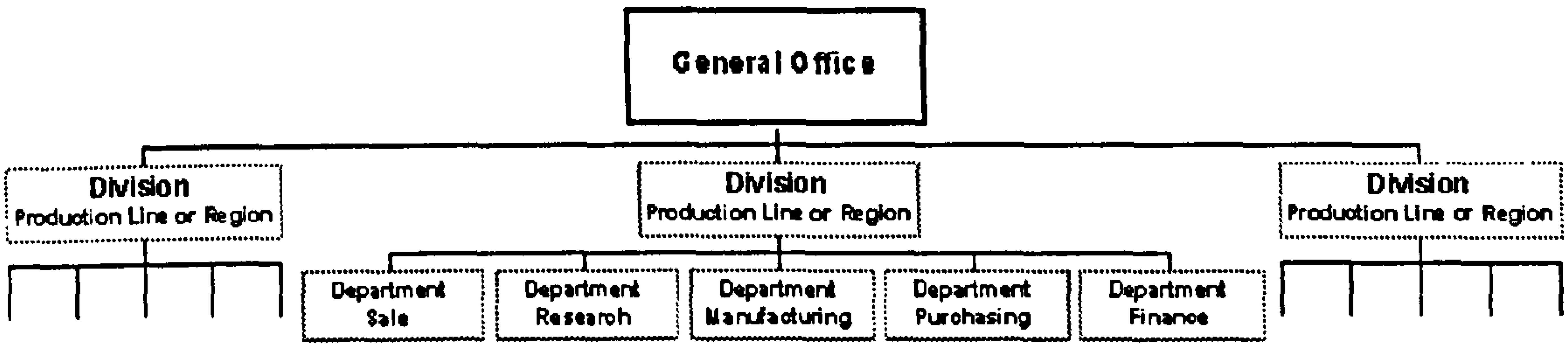


Figure 4.9 Multidivisional Form Organisation Structure

It is important to note that this organisational form is a scaled down form of the specialised U-form. However, Williamson (1975) argued that this simple change in structure required more requisites to be effective. The systems of control, planning, information flow, methods of reward and punishment, the degree of delegation and techniques of co-ordination are among the important changes that must accompany such an organisation restructure. The senior managers must be prepared delegate authority to help the organisation structure perform to its optimum, i.e. autonomous authority should be given to the operational divisions concerning operating duties and tactical decisions. This allows top executives to concentrate on the responsibilities of determining the best destiny and strategy for the entire enterprise. Figure 4.10 illustrates efficiency against complexity for both the M-form and U-form organisation structures.

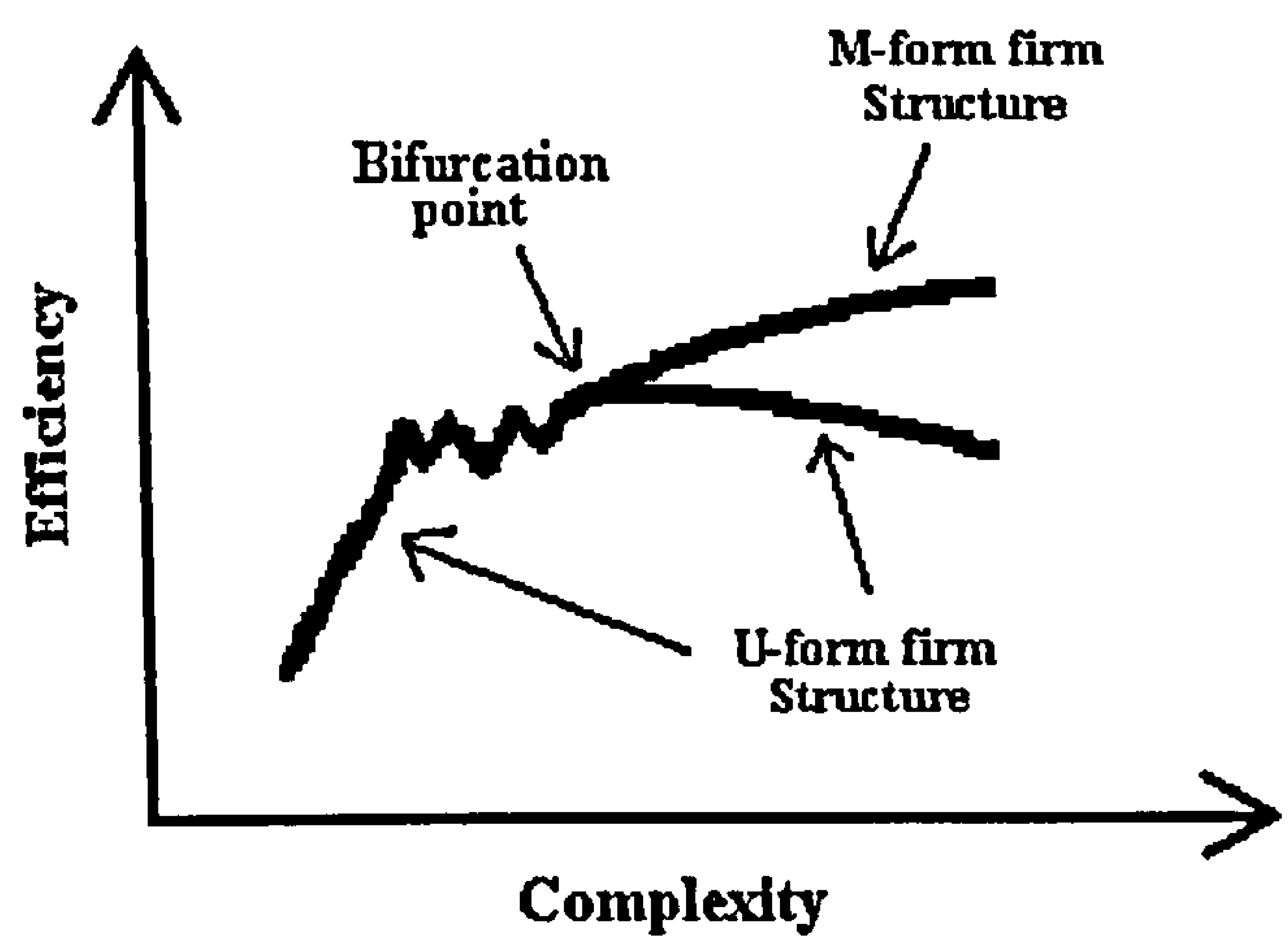


Figure 4.10 Efficiency for M-form and U-form Organisation Structures.

It is important to note that M-form structures only work if divisional managers are willing to act in such a way that will benefit the company as a whole. It is assumed that when a divisional performance is less than the intended one, the senior management will have the authority and resources to replace incompetent divisional managers. The disadvantages of M-form structures are that senior manager may recognise that divisionalisation can strengthen their grip on the levers of corporate power, also known as "power theory" (Pfeffer, 1981).

In a study to examine the effects of organisation structure, Fligstein (1985) compared the organisation structures in the large US companies that dominated the US economy between 1919 to 1979. Highlighted in his study, is the finding that only 1.5 percent of companies in the sample had M-form structure in 1929, but sixty years later, eighty per cent of organisations used this structure. Chandler (1962) and Williamson (1975) claimed that M-form structure had been created to deal with the growing complexity of managing large organisations. As companies, such as General Motors continued to be successful, this structure spread to other organisations who imitated in order to achieve better business performance. Although the spread was rapid, there is still much debate about whether it is feasible or beneficial for the company as a whole. Evidence provided by Hill et al. (1992) shows that M-form organisations may not improve the performance after the implementation or the restructure of company. This posed questions about what promoted the spread of M-forms. Some theories that attempt to explain this phenomenon include power theory (see Pfeffer, 1981) and population-ecology theory (see Hannan and Freeman, 1977).

By comparing companies in 20 different industries that adopted M-form structure against their competitors who did not have M-form, Teece (1981) discovered that companies with M-form organisation structure always performed better. In summary, M-form structure generally gives a superior performance in situations in which the organisation has many diverse products and a dynamic economic and technological environment. However, when this is not the situation Lawrence and Lorsch (1967) suggest that functional organisations tend to perform well or better than divisionalised organisations in a static or gradual changing environment and with limited product lines.

4.5.2 K-factor in Organisational Studies

Perelson and Macken (1995) attempted to modify the NK fitness landscape model to reflect more pragmatic applications. It was proposed that a "block" model that partitioned the N loci into B blocks could be used. They assumed that the loci within each block interacted epistatically with all other loci within that block and that there is no epistatic interaction between blocks. Also, they assumed that each block contributes independently to an overall fitness of the molecule. As the amount of epistatic interaction at a locus i depends on the number of loci in the block to which locus i belongs, the degree of correlation depends on the number of blocks. For instance, if B=1 then this model is reduced to the random landscape model which was discussed in the previous section of this thesis. It is similar to an NK model with K = N -1. If B = N, then the landscape is smooth with a maximum correlation, which is similar to an NK model with K = 0. Figure 4.11 shows an example of block partition.

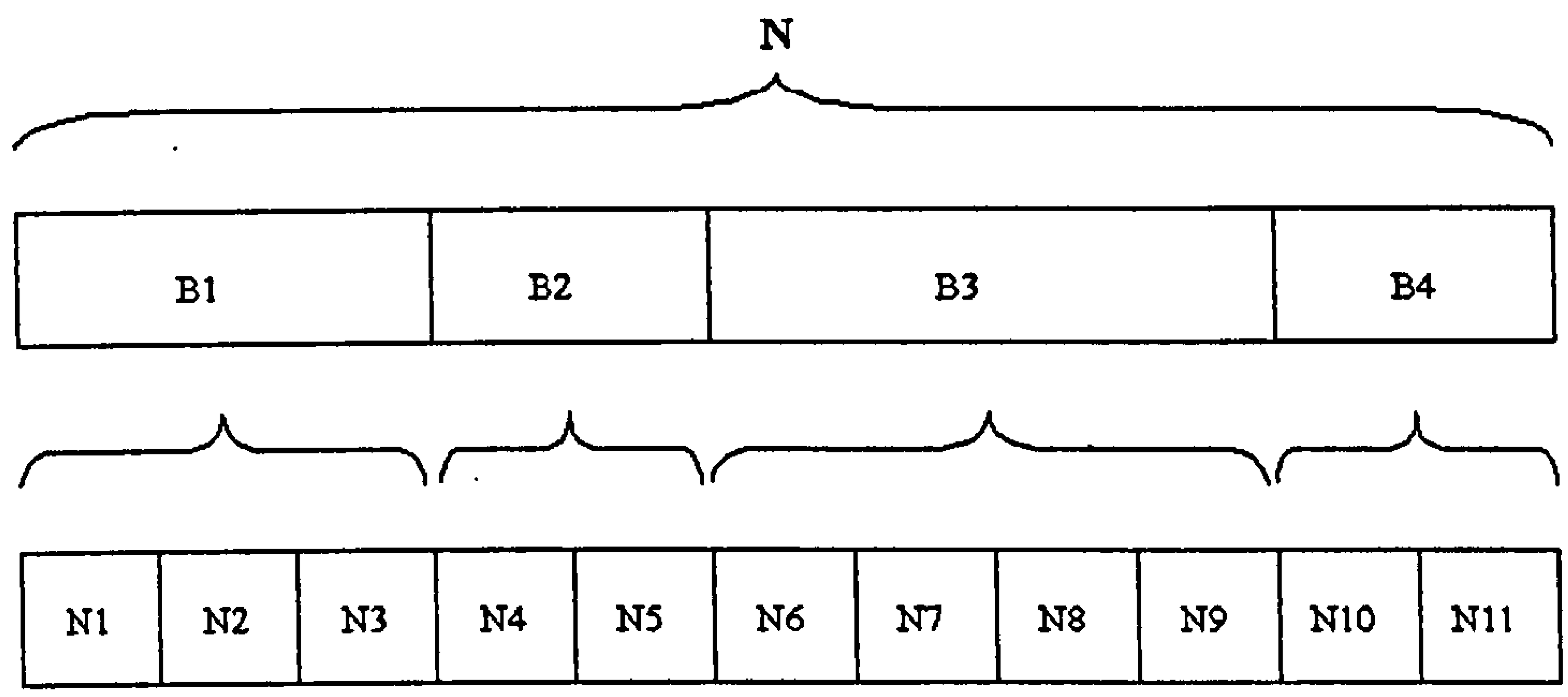


Figure 4.11 Block Partition

This modification of the NK model is similar to models found in management practice in organisation size and structure as discussed in the previous section. For a large N factor it is difficult to manage or even to obtain a relatively high fitness due to the conflicting nature of genotypes. In order to assist management, this problem is tackled by grouping similar operations into smaller parts or departments. These sub-units will then be optimised by some form of management, i.e. the M-form concept of division or the levels in organisations. This will make the whole organisation more manageable as optimal operation can be deployed to the sub-string. A divisional structure could be established to serve different market segments; to provide different products; focus on different geographic areas or utilise different production processes.

Table 4.4 shows a comparison between the notations that might be used in an evolutionary NK Model and an organisational fitness landscape model. Fitness landscape theory could benefit research into organisational structure as the theory provides insights into the usage of decentralisation. It could show that organisations with high levels of vertical central control are too rigid, not allowing enough time for commands to filter down to lower management. The traditional hierarchy and chain of command must be broken down so there is opportunity for more linking relationships that will encourage cross-functional partnership. Reducing layers of hierarchy can also offer the advantage of speeding up decision making (DuBrin, 1996), because with each layer of management, is a layer of approval, thus increasing the time required to make a decision. Also, with fewer management layers, lower level of management can communicate directly to top management instead of going through a massive chain of command. With rapid decision making, customer service may be improved.

Notations	Evolutionary Biology	Organisation Study
N	Number of parts or genes	Number of organisational elements such as departments, employees, machines etc.
K	Number of epistatic interactions	Number of interactions among organisational elements
A	Number of alleles	Number of possible selections
B	Number of block	Number of "independent" teams, departments, divisions etc.
W_i	Fitness values in evolutionary landscape	Fitness values in the organisational landscape
D=N(A-1)	Dimensions of the evolutionary landscape	Dimensions of the organisational landscape

Table 4.4 Comparisons between NK Model and Organisation Study

4.5.3 Increasing Returns in Fitness Landscape

Increasing returns are defined as the tendency for those who are ahead to gain further advantage; and for those who have lost advantage, to further lose it. The idea is similar to *positive feedback*, a term which is familiar in control-system studies. This is different from the traditional theory found in economic textbooks developed by the likes of Alfred Marshall more than one century ago. This theory stated that a market would become stable and in turn provide a diminishing return (Whitaker and Marshall, 1975). A good example, is when a company that has a good sales record attempts to expand its production. There will be a certain point when the company reaches its maximum output with its present capacity. To further increase its output, it has to invest in new machines, employ new workers, or even open up a new facility for the extra capacity. All of these options will diminish profit in the short term and therefore the market becomes shared by several competitors. With this competition, it is difficult to increase profit greatly above production costs. Therefore the price of the product becomes stable and no one company can corner the whole market. This theory works very well for the products that are heavy on resources, but light on knowledge. In the 1980s, Arthur (1996) proposed a different theory, which he identified from the increasing returns being achieved within the personal computer operating system market. In the 1980s, there were several operating systems for personal computers including: CP/M, DOS and Apple's Macintosh system. All of these systems had their advantages and disadvantages. At the time, PC users had several choices of different software written with different operating systems. There was no clear leader among the various competing platforms. Later, when Microsoft made a deal with IBM to supply DOS for their new PC; the situation changed. As IBM became the standard PC platform, it enabled many software writers to write software applications based on the DOS operation system, and this in turn strengthened the position of the IBM PC and the DOS operation system.

From theses events Arthur (1994) noted several properties of "increasing return". Firstly, the market is unstable, as it favours the product that gains an advantage. Secondly, there are several potential outcomes, as any competitor can be the winner if they have the advantage. Thirdly, the product can lock in the market, as it is very costly, if not (technically) impossible for other competitors to change the situation around. Fourth, the best product is not guaranteed to be the winner as many computer experts felt that DOS was inferior to its competitors. Fifth, a winner-takes-all situation surfaced. Finally, the product can become a standard in later developments.

In fact, the theory of increasing returns and lock-in has occurred several times in recent history. Another example is the combustion engine in the automotive industry. When the automotive industry started to expand, there were several competitors and at that time the steam-powered engine was the superior product. However, it was slow in reaching commercial development, unlike the combustion engine, which reached the market first and achieved the lock-in advantage. Another example is the clock - why does it travel in the 'clockwise' direction when the opposite direction of travel 'anti-clockwise', can work just well as the present system.

To summarise, the increasing returns and lock-in situation can be viewed as the C-factor which has been discussed in the fitness landscape theory. Organisations, intentionally or unintentionally, will alter the landscape in which they inherited. To survival in this competitive world, organisations must be able to improve continually. The next section will discuss some strategy to help organisations in this task.

4.5.4 Application of NK Model to Organisational Strategy

Maguire (1997b) suggested that an organisation's corporate strategy could be viewed using a NK Model. Table 4.5 distinguishes the elements that are found in organisational strategy and transfers them into rugged landscape terminology.

Organisational Terminology	**Fitness Landscape Terminology**
Product and resource characteristics	**Impact on Landscape**
A) "Inherent" product and resource design complexity	**A) Landscape topology**
1) parts or variables in engineering problem few parts => many parts few alternatives per part => many	**1) size [A^N] and dimensionality [N(A-1)] of combinatorial search space** low N => high N low A => high A
2) interdependencies with engineering problem: none (simple and decomposable) => many (complex) single evaluation criteria => multiple criteria	**2) landscape ruggedness:** low K => high K
3) interdependencies with other engineering problem in the economy independent => many interdependencies	**3) landscape coupledness:** low C => high C

Adapted from Maguire (1997b), pg. 13

Table 4.5 Corporate Strategy within NK Rugged Landscape Framework

Hence there are some strategies that could be derived from the fitness landscape theory as discussed in the following sections.

4.5.4.1 Strategies Derived From Fitness Landscapes Theory

Merry (1999) suggested some tentative rules of thumb for studying companies as complex adaptive systems using fitness landscape theory. These are:

1. In a rugged unpredictable environment, it is advisable not to invest in long term detailed strategic planning. Instead a company should try to develop tentative short-range plans and build on surveying what the present trends are. For example in the computer microchip industry, companies such as Texas Instruments, Fujitsu, etc. invested heavily on a long term basis in the machines/plants that produce DRAM such as 4M and 16M RAM. At the time in 1993, it was a sensible strategy as the price of the chips was around US$60 each. However, dramatic changes in the computer industry meant that chip price fell to U$1 in 1998. This severely affected the companies' profits between 1993-98 (Pullin, 1998).

2. Companies should observe and monitor trends that are developing now, with a view to taking advantage of fad waves or windows of opportunity. When these situations arise, companies should have the ability and resources to respond. Bill Gates of Microsoft saw the launching of digital television as a threat to the Windows PC empire, especially for the Internet-user's market. This is mainly due to the fact that digital television has the ability to transmit information faster through cable, instead of a 28K modem for the present connection through the telephone line with a PC. Microsoft's response was to assign resources into this area and attempt to turn this to the advantage of the company (Barnard, 1998).

3. If a company has average fitness, then it may be worthwhile searching in remote and distant areas of the landscape. As fitness increases, the company should focus its search closer to its immediate environment.

4. When the company is "trapped" in a valley or hill, it should create noise by doing unaccustomed things such as breaking the company into independent interacting parts and ignoring some of the constraints and traditional practices that placed the company in this position. Semler (1993) reported that his company, Semco underwent some reforms that were considered unconventional. These reforms included allowing staff to determine their own working schedules, salaries and bonuses. Such practices led Semco to become one of the leading manufacturers in Brazil.

5. A company which has technology dominant products should strive to create the standard, so that all further developments in that field will be locked in to it. Microsoft has been thriving for the past two decades because it managed to turn its products, first DOS, then Win3.11, Window 95, Window 98 etc. into a standard in PC operation systems. By locking itself in as a standard product in PC, users are reluctant to switch to other systems.

4.5.4.2 Several scouts

Beinhocker (1999) suggested that while companies might concentrate their resources on a single strategy at one time, they must also build and maintain a list of strategic options for the future. By making investment decisions based on a single option, companies could find themselves over-investing in one area and push themselves into a corner of the fitness landscape. In his metaphor Beinhocker used "several scouts to explore the landscape". This is consistent with the strategic approaches that have been adopted by some car industry leaders, that have tried to promote several car models, rather than just one, and then rely on market and customer forces to decide on which car model will be bought. This strategy is assisted by the fact that current agile technology and working practices permit the effective manufacture of ever changing car models. Financially, it was pointed out by Worrall (1999) that although the starting up cost is higher than the traditional method ("*get it right the first time*" as the author put it), this strategy contains lesser risk. This is because a company can have full investment only when the new product has been proven successful. When the winning product takes off, the company can then further invest in production technology to bring the cost down, further optimising production operations.

4.6 Conclusion

This chapter provides an overview of fitness landscape theory and its potential application management and organisational science. With this introduction and explanation, organisational researchers should be able to relate this concept into specific manufacturing terms.

A simple manufacturing example was used to illustrate fitness landscape theory and therefore associate fitness landscapes with manufacturing issues. A detailed account of the theory was provided to introduce and explore the significance of internal and external connectivity (K and C factors). Finally the third section showed how the theory could be related and applied to organisation design (structure, size) and the strategies that could be deployed to ensure high levels of fitness.

The conclusions from this discussion are

- Organisations evolve and many factors such as size and structure are adopted to help organisations survive.
- Size and structure are two factors which are highly connected and would therefore relate to the concept of internal connectivity, K.
- "Increasing returns" and "lock-ins" are examples of external connectivity, C.
- Researchers such as Maguire (1997a, 1997b) and Merry (1998, 1999) have made the link between fitness landscape theory, but did not create a definition and model that can be applied to organisations.

In summary, fitness landscape models show how different organisations react to the action and behaviour of others. The behaviour of one organisation could (intentionally or unintentionally) alter the face of the landscape and therefore influence the evolutionary behaviour of other organisations. Also, this model helps to explain the different stages of co-evolution, by understanding levels of internal-connectivity (K factor) and external-connectivity (C factor). Finally, fitness landscape models show that co-evolution can be orderly, chaotic, at the edge of chaos or self-organising. However, with tools such as fitness landscape, benchmarking, strategic groups, mobility barriers, value chains, etc. the goal should not be to find the niches in existing landscape areas, but to create new space on the landscape in unexplored areas. It is these territories that the company should explore to ensure that maximum benefits are gained (Hamel and Prahalad, 1989).

The literature review presented in this chapter, reveals that the community of researchers working on the fitness landscape concept, obviously use the word "fitness" frequently but they do not define the term or relate the concept of biological fitness to a possible definition for business fitness. This reluctance to define this word "fitness" is clearly detrimental to the further understanding and application of fitness landscape theory. This is especially so for business entities such as manufacturing organisations. Thus, this thesis aims to rectify this casual usage of the word "fitness" by investigating this word in a greater detail and to propose a working definition of fitness, organisational fitness and manufacturing fitness.

Chapter 5. The Concept of Fitness

In the last chapter, the concept and usage of fitness landscape theory were discussed. In order to develop this idea further, a definition and function of fitness for manufacturing organisations needs to be established. Thus, the main objective of this chapter is to discuss in further detail the concept of fitness and create this definition and function.

The chapter will begin by examining the various definitions of *fitness*, particularly in relation to its origins in biology. From this literature review, a purely biological definition of fitness in an evolutionary context will be provided. The next section will present and discuss a definition of *organisational fitness* and how this relates to profits, organisational competitiveness and organisational effectiveness. This section will conclude with a definition of organisational fitness which will be used throughout this research. The last section will deal with *manufacturing fitness*. It will refine the definition of organisational fitness into one that has a manufacturing context and relevance. It will also propose the outline of categories and characteristics that could be used to evaluate manufacturing fitness.

In summary, this chapter will

- present a definition of fitness in biological studies,
- present a evolutionary perspective of organisations, and
- present a definition of organisational and manufacturing fitness.

5.1 Biological Fitness

In order to define a fitness function in a manufacturing context, a literature review was first conducted to determine the definition of 'fitness' in biological and evolutionary studies where the term originated. Although the term is regularly used in these literatures, the definition of and use of the term still has a degree of ambiguity. A major problem is that there appear to be various concepts of fitness in the literature and there is no agreement on a common definition among different authors. Some authors observe that a universally understood meaning of the term is often assumed, but themselves avoid providing an accurate definition of their own. Many authors assume that the word is well known by the reader, and avoid defining it precisely. However, they then assume that an optimisation of this fitness is possible, and go on to consider what genotype is selected to obtain the best solution. This problem has been pointed out by Stearns (1976) who stated that fitness has not been defined precisely, but that everyone seems to understand it. The lack of a clear-cut definition provides both a problem and an opportunity for researchers who shoulder the burden of developing their own concept of diversification, while enjoying the freedom of tailoring a concept to suit their interests. As a result, researchers in different fields have created different definitions for the word 'fitness'. Prior to identifying what these different definitions are, the relation between fitness and natural selection is discussed in the next section.

5.1.1 Natural Selection?

Over a century ago Darwin proposed that natural selection was the driving force of evolution. Selection refers to the inherited differences in an organism's ability to survive and hence to reproduce, so that through time the genotypes that are superior in survival and reproduction increase in frequency in the population. Selection results in greater adaptation of organisms to their environment, because through adaptation the inheritance of traits that enhance survival and reproduction in a given environment is possible.

As Endler (1986) stated, the presence of three conditions is necessary for the process of natural selection to occur. These are well known in biological science, and are:

1. **Phenotypic variation**. Individual organisms in a population will show different characteristics, morphologies, physiologies, and behaviour;
2. **Differential fitness**. Among these individual organisms, there are different rates of survival and reproduction in different environments;
3. **Heritability of fitness**. There is a correlation between parents and offspring in the contribution of each to future generations, independent of common environmental factors.

For example, if all zebras ran at the same speed, there would be no variation on which selection could act. They would all have an equal chance of being captured by their predators. If however, some zebras managed to run faster, and this variation helps to avoid capture, these zebras would reach maturity and produce offspring. In other words, their fitness has been increased. If running speed does not enhance survival or production, then natural selection would not favour faster zebras over slower ones. However these conditions alone are insufficient, this variation must also be heritable. Under the assumption that the gene which controls the speed of the zebras is heritable, the faster zebras might produce faster offspring than the slower parents could. Furthermore, the fact that the faster zebras could produce more offspring than the slower ones increases the number of faster zebras. As a result, the proportion of faster zebras against slower zebras will increase in time. Evolution by natural selection requires that the evolving traits be heritable.

The conditions that make natural selection feasible express the idea that different characters have different reproductive potentialities in a given environment. Therefore, Arnold and Fristrup (1982) refined the third observation into two distinct statements.

3a) There is a similarity between parents and offspring in their characteristics, morphologies, physiologies, and behaviour;

3b) There is a link between the character-dependent interaction of the organism with its environment, and this interaction determines fitness.

Arnold and Fristrup (1982) used the above statements to highlight their view that the concepts of "character" and "fitness" are not equivalent. In the above zebra example, natural selection is a continuing process that results from biological differences among individuals. These differences may give rise to genetic change or evolution. Therefore, natural selection has a rate and rate coefficients, which are estimated by fitness. Consequently, fitness should be seen as a description rather than an explanation. In the coming sections, the concept and meaning of fitness will be introduced.

5.1.2 What Is Fitness?

The term fitness was first used by Herbert Spencer in 1864 in the context of 'survival of the fittest' with respect to the idea of 'natural selection' as proposed by Darwin in his *Origin of Species* four years beforehand (Gould, 1991). In a later edition of the same book, Darwin used the two phrases interchangeable and later, it became widely known as *Darwinian fitness*. In this context, fitness is roughly the capacity to survive and reproduce. It was not until 1930 that Fisher (1930) related *fitness* to the organism's reproduction rate although he himself did not define fitness. The reproduction concept then became widely used in population ecology and organisational ecology studies. Dawkins (1982) identified five definitions of fitness widely used in the literature:

a) Darwin's fitness

The fitness used by Darwin and Spencer did not have a precise technical meaning (Gould, 1991). The term roughly meant the capacity to survive and reproduce, and it was not defined or evaluated as a precise measurement such as reproductive success. However, the "fittest" organism is said to be the individual that produces the largest number of offspring to survive to maturity and reproduce. This fitness is also known as Darwinian fitness, selective value and adaptive value (Allaby, 1999).

b) Fitness defined by population geneticists.

There was no formal definition or measurement of the term *fitness* until 1930 when Fisher (1930) made an attempt to link it to the relative rate of increase (or decrease) of a population. Fisher did not define *fitness* itself, making the assumption that it was a concept generally understood by everyone. Subsequently for population geneticists, fitness has become a practical measurement, not relevant to a whole individual organism, but to a certain genotype at a certain locus. It may be referred to as a measurement of the number of offspring that a typical individual is expected to bring up to reproductive age, when all the other variables remain unchanged or are averaged out. The focus of this measurement is in the changes in genotype frequencies and gene frequencies that occur in the population. For example, if two populations have different sets of genes and accordingly have a different relative rate of increase, the population which has the larger rate of increase also has greater fitness. If more white sheep are raised than black sheep, then the fitness of white sheep is greater than that of black sheep. This measurement of expectation of reproductive success became an orthodox view of Darwin's fitness.

c) Fitness defined by ethologists and ecologists.

Ethology and ecology are two fields of biology that aim to study the reactions and relationships of a given organism to its environment. Researchers in these two areas treat the organism as an integrated system that is searching for an optimal solution in an open environment. Fitness is defined here as a property of the individual organism, often represented as the combination of survival and fecundity. It is used as a measurement of how successful an organism is in reproducing offspring, or its success in passing its genes on to the future generations. The fitness of an organism is usually measured as the number of its offspring reared to adulthood as a means of showing the parental care of the organism. However, there are some disputes over the usefulness of this definition. Firstly, this measurement will be gathered, if at all, only when the subject of interest is deceased or has past its productive period. This is due to the linking of the definition to the number of offspring to reach adulthood. Therefore, this measurement will not be useful in predicting or projecting the condition of the organism while it is alive. Secondly, the rearing of offspring to adulthood is not just based on the ability of the parents, but also on other important influences, such as the environment.

d) Inclusive Fitness defined by Hamilton

Hamilton (1964a, 1964b) developed inclusive fitness to explain how altruism could have evolved. He reasoned that close relatives, like siblings, parents, and children will have at least 50% of their genes in common. Therefore, a sacrifice that gives more than twice as much benefit to a relative will have an indirect net reproductive benefit to the genes, via the relative's offspring. This concept led to the famous statement made by J.B.S. Haldane (1892-1964): "*I would lay down my life for two brothers or eight cousins*" (Gould, 1991). The reproductive success that accounts for both direct and indirect (via relatives) reproduction is called "inclusive fitness". While it may have questionable relevance for the study of humans and higher mammals, this concept has been useful in trying to understand the life of bees, wasps and ants. Most members of these species are sterile and cannot sexually reproduce and their lives involve caring for a 'queen' which lays eggs within the colony, and her offspring. Worker females have to give up reproduction and raise their mother's offspring. Inclusive fitness is said to be maximised by the behaviours of the organism over a lifetime in such a way as to leave as many copies of its genes, or alleles to the coming generations as possible. Inclusive fitness can be defined as the sum of individual reproductive success and the reproductive success of an individual's relatives, with each relative devalued in proportion as it is more distantly related. In other words, inclusive fitness is said to be sum of the individual's own fitness plus half the fitnesses of each brother plus one-eighth of the fitness of each cousin, etc.

e) Neighbour modulated fitness defined by Hamilton

Hamilton proposed another definition of fitness, known as *neighbour modulated fitness*. (Hamilton, 1964a, pg. 2-5). This type of fitness he defined as the expected number of direct offspring produced by an individual. Compared with inclusive fitness, this fitness is difficult to calculate (Hamilton, 1964b; Maynard Smith, 1982). However, Hamilton also suggested that when used carefully and subjected to certain assumptions, both *inclusive fitness* and *neighbour-modulated fitness* would arrive at the same conclusion. It is possible that Hamilton himself may have preferred the use of *inclusive fitness* and abandoned the use of *neighbour-modulated fitness* due to this unwieldiness (Maynard Smith, 1982). However, the main difference between the two definitions is that the former tends to concentrate on the effects the individual of interest has on the fitness of his relatives, whereas the latter tends to emphasise the effects that relatives have on the individual's fitness. For this reason, this type of fitness is also known as *personal fitness* (Orlove, 1975).

In listing these five definitions of fitness, Dawkins (1982) remarked that the last three treat the subject of interest as some sort of agent trying to optimise something. For inclusive fitness and neighbour-modulated fitness, the genes are even assumed to have some intelligence and the intention of maximising their survival or increasing the number of replications of its genes. This may cause confusion among researchers as genes are not regarded as maximising agents.

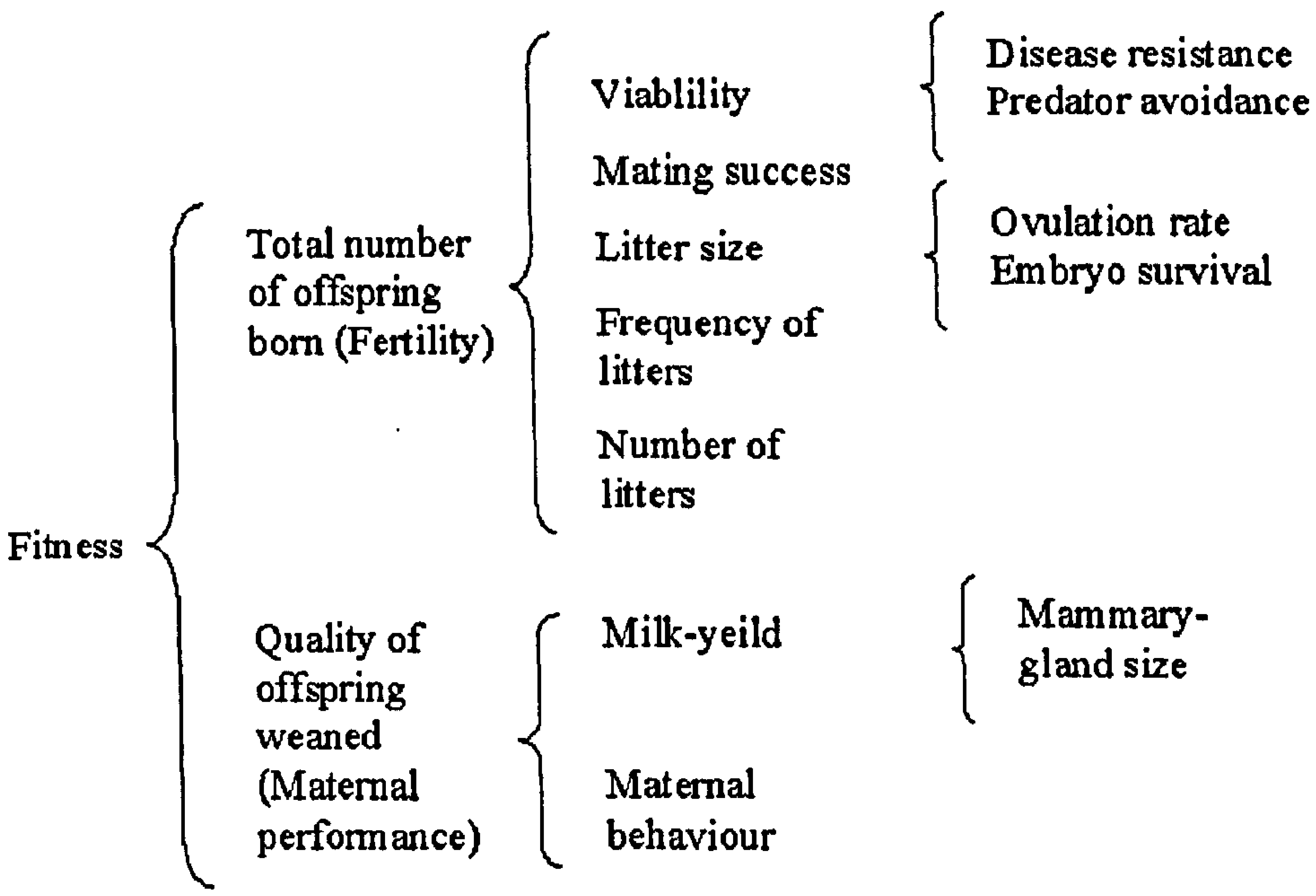
Endler (1986) proposed five contexts in which the term fitness may be applied: Darwinian fitness, rate coefficient, adaptedness, adaptability and durability (see Table 5.1).

Term	Definition and measurement	Remarks
Fitness	The degree to which condition 2 for natural selection (discussed in pg.79) is true. It is measured by the average contribution to the breeding population by a phenotype, or of a class of phenotypes, relative to the contributions of other phenotypes.	Also known as Darwinian fitness, relative fitness, and selective value. Selection coefficient and selection differential are algebraically related to fitness.
Rate coefficient	The rate at which the process of natural selection proceeds. Measured by the average contribution to the gene pool of the following generation, by the carriers of a genotype, or by a class of genotypes, relative to the contributions of other genotypes.	Similar to the fitness defined above, but also includes the genetic response.
Adaptedness	The degree to which an organism is able to live and reproduce in a given set of environments; the state of being adapted. Measured by the average absolute contribution to the breeding population by a phenotype or a class of phenotypes.	Also known as absolute fitness. Is also applied to species, where it is known as the Malthusian parameter.
Adaptability	The degree to which an organism or species can remain or become adapted to a wide range of environments by physiological or genetic means	The reverse of specialisation.
Durability	Probability that a carrier of an allele or genotype, a class of genotypes, or a species will leave descendants after a given long period of time.	Best expressed for alleles, genotypes, or species by the expected time to extinction.

Adopted from Endler (1986), pg. 40

Table 5.1 Five meanings of fitness

From these definitions, an organism's survivability and reaction through adaptability and durability to the changing environment are made clear. Fitness is therefore defined mainly to provide a measure of prediction of the composition of a population in terms of trait frequencies or the composition of the genotype components in the long term. Such predictions tell us what type will prevail, or whether many types will remain present, on the basis of the reproductive parameters that could be observed as associated with that type. Population geneticists would associate fitness to the observable effect, i.e. the reproduction rate of the species, and the history of the species. For example, Lincoln et al. (1998) defined fitness as *"[t]he relative competitive ability of a given genotype conferred by adaptive morphological, physiological or behavioural characters, expressed and usually quantified as the* *average number of surviving progeny of one genotype compared with the average number of surviving progeny of competing genotypes; a measure of the contribution of a given genotype to the subsequent generation relative to that of other genotypes."* In this definition, the fitness is a summary of different factors of the genotype that the offspring can benefit from. Figure 5.1 which has been adopted from Falconer (1981) illustrates the different characters and levels that could contribute to a fitness of a female mammal.



Adopted from Falconer (1981), pg. 337

Figure 5.1 Components of fitness of a mammal

This particular type of fitness measurement can only be calculated when the number of surviving offspring of the mammal under study are at hand. As fitness is intended to be a predictor tool, some researchers (for example, see Dawkins (1982), pg. 180) have claimed that this way of defining fitness is a tautology. The tautology is created as the term fitness is used just to measure the reproduction rate or number of offspring and not as an *expectation* of reproductive success of the organisms. To say that organism *A* is fitter than organism *B*, means that organism *A* produces more offspring than organism *B*. However, this does not explain why organism *A* has been selected to produce more offspring. As the tautology problem associated with this fitness definition lies within the *post factum* success as indicates in the *actual* number of offspring produced by an organism, therefore if fitness is interpreted as the *propensity* of an organism to leave offspring, the tautology disappears. In his paper, Cheetham (1993) referred to fitness as " *the probability that the members of a species will all survive to the next generation*". He used the probability of reproductive success, rather than the actual reproductive success of a genotype. In his book, Brandon (1996) even used *adaptedness* to refer to the expected fitness value, while *fitness* refers to the actual reproductive success. In another paper, Arnold and Fristrup (1982) distinguished between the fitness and success of an organism by expressing "*fitness as an expectation of net reproductive success rather than the realised post factum success*" (pg. 116). They further defined success as "*measured by the rate of increase in absolute numbers of descendent, ... This value is a retrospective measure of the relative increase or decrease in the descendent of a lineage, as a fraction of a specified population over a specified time interval.*"(pg. 119). Fitness is expressed as an expectation of success rather than as being the real success to be fulfilled and measured *post factum*.

5.1.2.1 Discussion of Biological Fitness

In the above sections, a tautology is caused as fitness is treated as a tool to predict or forecast the frequency of genes into the future. In order not to fall into this tautological pitfall, the definition of fitness that follows in this thesis will not be used for prediction, but will be a measurement to describe how successful the subject of interest is with respect to others in the same environment. It is a description rather than an explanation.

5.2 Organisational Fitness

Before the fitness of a biological organism can be defined, the purpose of its existence must be clarified. There is general agreement that the two main aims of an organism are to survive and reproduce. Therefore, fitness measures the success of the organism by the number of offspring it is able to produce. In applying the concept of fitness to the study of organisations, their purpose has to be studied and well understood before any attempt to define their fitness can be made.

Consequently, an appropriate definition for the existence of an organisation will have to be determined. It must be noted here that organisations can be divided into profit-making i.e. business organisations, and non-profit organisations such as schools, hospitals, and charities. In this thesis, the main focus is on profit-making organisations.

This section is divided into three parts. The first part reviews the rich literature on organisational effectiveness. This review is used as a stepping stone to understand organisational purpose. The second part looks at and discusses the analogy between organisations and organisms from an evolutionary perspective. The last part brings these two discussions together and relates them to organisational fitness.

5.2.1 Organisation Effectiveness

A common criticism of the literature on organisational effectiveness is that it is fragmentary and non-cumulative. Researchers carrying out reviews in this area have found that there is a lack of integration of ideas. Some researchers, for example Campbell (1974), Steers (1977) and Price (1968), have assembled lengthy lists of criteria that have been used by one or more analysts in measuring effectiveness. Reviewing studies that focused on a single criterion of organisational effectiveness, Campbell (1974) managed to identify 19 different variables used. He later proposed and listed 30 different criteria that may be used to measure effectiveness (Campbell (1976). These measurements range from productivity and profits, to growth, turnover, stability and cohesion. In another publication, Steers (1977) limited his attention to 17 studies of organisational effectiveness in which multiple criteria of effectiveness were devised. He found that the five most common criteria of effectiveness are adaptability-flexibility, productivity, satisfaction, profitability and resource acquisition (see Table 5.2).

Evaluation Criteria*	No of times cited*	Definition +
Adaptability-Flexibility	10	The ability of an organisation to change its standard operating procedures in response to environmental changes.
Productivity	6	The quantity or volume of the major products or services that the organisation provides.
Satisfaction	5	An individual's perception of the degree to which he or her has received a reasonable amount of the outcome that is provided by the organisation.
Profitability	3	The amount of revenue from sales left after all costs and liabilities are met.
Resource acquisition	3	The extent to which the organisation successfully interacts with its environment and acquires scarce, valued resources necessary to its effective operation.

Adopted from * Steers (1977), pg. 46; + Campbell (1976), pg. 36-37

Table 5.2 Effectiveness Criteria

Steers (1977) pointed out that from these comparisons of multivariate models, there is a lack of consensus as to what contributes to an effective organisation. He also noted that while each model set forth its 3 or 4 defining characteristics for success, there is little overlap across the various approaches. This drawback may be due to the diverse and self-understanding of organisations that is held by various analysts. To evaluate these distinctive concepts, different criteria are used. Furthermore, Seashore (1962) pointed out that organisations at different stages of the organisational cycle will have different criteria or aims for growth, survival and overall effectiveness. For example, highly specialised organisations may perform better than general organisations in the short term, but in the long run the former may progress less well than the latter as the environment changes (Ruef, 1997). On the basis of this, it is possible to say that organisations that learn effectively and are less rigidly specialised, may be better adapted to the environment overall, where that environment is dynamic. When the world changes greatly, specialised organisations will not be able to adapt to the new environment. This could result in their extinction and hence create an opportunity for new organisations to evolve and grow. These new organisations will then become specialised to the environment and the cycle goes on (Levinthal, 1996).

Recognising that a universal model of organisational effectiveness relevant for all organisations is a never ending task, researchers seek to identify the purpose of the organisation before defining its organisational effectiveness. Cameron and Whetten (1983) edited a volume that presented different perspectives and models of organisational effectiveness, by authors from different academic disciplines. This volume provides a basis for comparison of these different models and can be used to explore the comparative strength and weakness of each model.

In another study, Scott (1987) recognised that organisations can be viewed using three different perspectives: rational, natural and open system. He distinguishes the need for different criteria to define organisational effectiveness from each perspective. Assessing the organisation from an open systems perspective, Seashore and Yuchtman (1967) described the effectiveness of an organisation as "its abilities to exploit its environment in the acquisition of scarce and valued resources" (pg.898).

5.2.1.1 Organisations in Open System Perspective

As discussed in Chapter 3 and presented in Figure 3.2, organisations are not closed systems that are isolated from their surroundings and environment, but are open to and dependent on flows (of personnel, energy, raw material and other resources) from outside. Furthermore, they interact with their environment. In viewing organisations as open systems, Scott (1987) defined them as "coalitions of shifting interest groups that develop goals by negotiation; the structure of the coalition, its activities, and its outcome are strongly influenced by environmental factors". (pg.23)

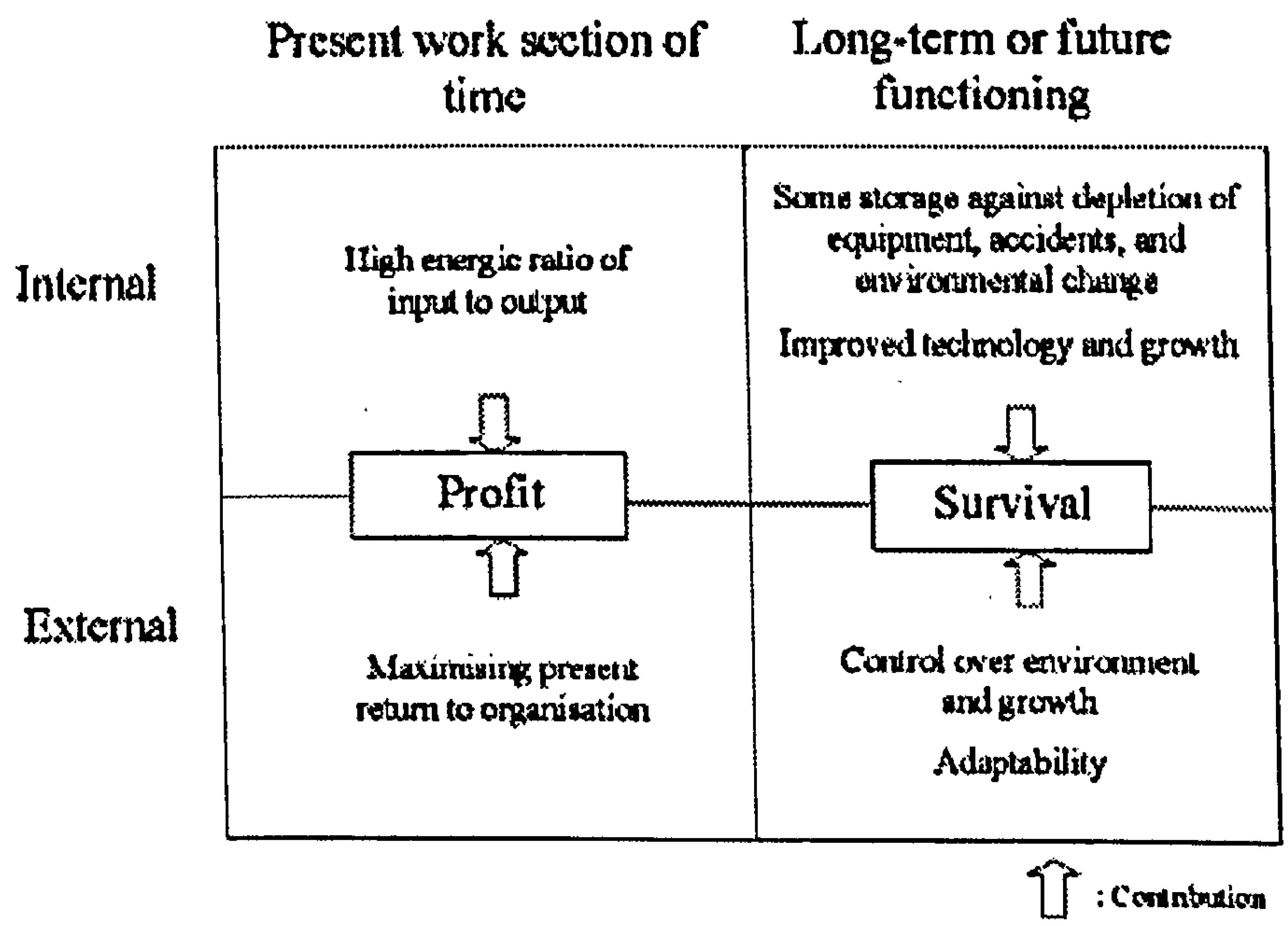
Under this open systems concept, organisations are viewed as highly interdependent with the environment and engaged in systems-planning as well as system-maintaining activities. In order to ensure their existence, organisations have to develop the ability to detect and hence respond to the changing environment. Information acquisition and processing are important tools to capture and notice these changes. With these abilities, organisations can then turn this knowledge into realistic assets. Therefore, criteria such as profitability, which may be defined as the excess of returns over expenditures, are emphasised by the open system analysts.

Another indicator of effectiveness is time scale. The criteria used to evaluate an organisation may vary depending on whether it is of a short or long time frame. Steers (1975) noted that while an organisation may be effective at maximising short-term effectiveness criteria, this may be at the expense of its future. For example, the profitability of a manufacturing organisation may be maximised by not investing in newer technology or by terminating a product development program. In the longer term, the consequence is that the company may find itself with an outmoded product range and its survival threatened.

As the above example illustrated, short-term criteria have a limited relevance for the measurement of organisational effectiveness. Organisations cannot devote all their energies and resources in achieving profit. They must also allocates energies and resources to the maintenance of the system itself. As a result, organisations are viewed as self-maintaining systems that must satisfy a certain set of internal needs. Simultaneously, they must also adapt and respond to the external environment (Katz and Kahn, 1978)

Successful organisations are seen to adapt to survive in their particular circumstances. When faced with difficulties, they do not just dissipate, but find ways to overcome circumstances, even if this means giving up some short-term intentions. If survival is at risk, the organisation will abandon the pursuit of declared objectives in order to save itself (Scott, 1987). For example, in the event of an exhausted market for a product or service, the successful, adaptable organisation will invest into new markets and not just stop trading. The move will deflate the organisation's short-term objectives such as profit, but will help ensure its survivability. On the basis of this, Katz and Kahn (1978) remarked that the behaviour of organisations indicated that survival was regarded as a major goal (pg.244).

Katz and Kahn (1978) divided their description of organisational effectiveness into two components - political advantage and economic efficiency. They then classified two types of time frame - present and future function. This produced a two by two matrix of organisational effectiveness. Later, some scholars, such as Hirsch (1998) and Wieland and Ullrich (1976), further clarified that the "political advantage" as described by Katz and Kahn (1978) entailed interaction with the environment such as influences by suppliers or the ability to attract customers. These are summarised as *external* factors. As for the term "economic efficiency", Hirsch (1998) and Wieland and Ullrich (1976) explained that the term includes internal activities that could be more easily controlled by the organisations. Therefore, a diagram taken from Katz and Kahn (1978) can be adapted and presented in Figure 5.2.



Adapted from Katz and Kahn (1978), pg. 249

Figure 5.2 Short and Long-Term Functioning of Organisations

5.2.1.2 Survival

The previous discussion indicated that if all organisations have one goal in common, then that goal is survival (Pfeffer, 1978). Survival here means "continuation of existence" without being "liquidated, dissolved or discontinued" (Kay, 1997, pg. 78). Kay (1997) further argues that the survival of an organisation in this instance is regardless of internal changes. These internal changes can take the form of replacement of the leaders (changes in the board of directors), organisational structure (U-form to M-form), products, organisation task (for example, Nike from manufacturer to brand marketer), or even its changes in organisation name (for example, British Gas to Centrica). Therefore, in Kay's point of view, even a merger or acquisition indicates that the organisation concerned has value to continue its business and hence "survive".

Organisations obtain the resources to continue the cycle of input acquisition and production through the selling of their output in some form of market. Sales of products or services are crucial for the organisation to continue in existence. Provided that organisations operate in markets with at least one or more competitors, the customers or clients engage in these transactions voluntarily. They are able to withhold their custom from organisations that they perceived are not providing satisfaction in terms of deals or services. An organisation that is able to increase its financial assets, for example capital, will face less pressure for its survival. Pfeffer and Salancik (1978) accordingly state that "growth enhances the organisation's survival values, then, by providing a cushion, or slack, against organisational failure" (pg.139). However, Sastry (1995) cautioned that the speed and tolerance with which the environment penalises an organisation's poor performance must also be investigated and known. The model assumes that the survival of the organisation is linked to its performance. Except in the case of merger or acquisition, organisations cease to exist when they are unable to meet their financial obligations. However, although this may be true in most cases, Meyer and Zucker (1989) cautioned that their study of failing organisations showed that there may be some exceptions to this. Meyer and Zucker found that owners of some private organisations would choose to terminate the business if the organisation's performances were low for a prolonged period.

5.2.1.3 Profit and Growth

It is assumed that investment decisions are guided by opportunities to make money, in other words that organisations are in search of profits. Investors perceive the potential of an unexplored territory or niche, and analyse the risk of profit or loss against the investment needed. If the risk is sustainable, a business organisation may be set up to exploit the situation. If a business is successful, the value of sales of its products will exceed what has been put up in net worth and costs. From this point in time, there will be a net addition to net worth, some of which is realised as profit.

The profit generated may be used to re-invest into the organisation, or be partly paid out to the owners as dividends, an act that may assure their future investment if necessary. In general, the financial and investment decisions of organisations are controlled by a desire to increase total long-run profits. By investing the profit back into the organisation, managers hope that profits in the future will grow with respect to the investment made. The assumption that the managers of organisations wish to maximise long-run profits evolved from investment in the organisation itself has an interesting indication for the relation between the desire to grow and the desire to make profits. Management has to balance investment and profit generated for owners. Logically, there should be a linkage between growth and profit as organisations will never invest in expansion for the sake of growth if the outlook of return is gloomy. To increase total long-run profits of an organisation, is equivalent to increasing the long-run rate of growth.

Pfeffer (1978) argued that the growth of organisations is another generally agreed upon objective, apart from survival. Growth occurs when an organisation reinvests its profit or surplus back into its system. By buying new plant and equipment or investing into new technology, employing more labour, the capacity of the organisation may be increased. With increased capacity, organisations can meet higher levels of demand and may be able to gain a greater market share. As a result, financial income may increase. As this business cycle is repeated, organisations can strengthen their position in the market. This growth is sometimes referred to as organic growth, as organisations employs more people (Campbell, 1997).

Organisational growth increases the likelihood of survival. Unlike small organisations, the social impact of a large organisation folding is such that political intervention may be introduced to prevent such an event (Pfeffer, 1978). Growth also provides two other advantages. First, more resources are shared among its participants and this results in less conflict internally. Second, organisations will gain more power in relation to other organisations, and this in turn leads to greater control of the environment and greater access to resources (technology, suppliers, workers, etc.)

5.2.2 Evolutionary Perspective

In the animal kingdom natural selection often means that weaker animals in the same species may die due to predators, starvation, etc. While in an organisational context, the consumer and market forces influence the role of natural selection. Fitter companies edge out the less fit companies by reducing their ability to win business contracts and orders.

With this brief introduction the market environment acts as a form of natural selection, linked inevitability to the organisations ability to survive and grow in that environment (Nelson and Winter, 1982). Penrose (1959) however, cautioned care in the use of the concept of natural selection to organisations. In biological studies the offspring should have an inheritable variation from the previous population. Penrose pointed out that organisations do not possess this genetic material in DNA form and so it is not a simple case of transferring these concepts from biological studies to organisations. Other researchers suggested however that although organisations do not posses DNA, it may be possible to encode this type of information in the form of *configurations* and *routines*. For example, Miller (1996) and Maguire (1997a, 1997b) proposed that configurations included the strategy and structures of the organisation. Also, Nelson and Winter (1982), used the term *routine* to refer to a repetitive pattern of activities which are consistent and predictable about business behaviour in an entire organisation. Thus, routines range from specific technical procedures to strategies and policies. In their book, they also suggest that as a company grows, it would retain past successful experience in the form of routines.

5.2.2.1 Routines

Levitt and March (1988) defined routines as "the forms, rules, procedures, conventions, strategies, and technologies around which organisations are constructed and through which they operate" (pg. 320). Aldrich (1999) used routines as a generic term that could be used to describe an organisation. Building on the same idea, March (1999) comments that:

The generic term "routine" includes the forms, rules, procedures, conventions, strategies, and technologies around which organisations are constructed and through which they operate. It also includes the structure of beliefs, frameworks, paradigms, codes, cultures, and knowledge that buttress, elaborate, and contradict the formal routines. Routines are independent of the individual actors who execute them and are capable of surviving considerable turnover in individual actors.
The experiential lessons of history are captured by routines in a way that makes the lessons, but not the history, accessible to organisations and organisational members who have not themselves experienced the history. Routines are transmitted through socialisation, education, imitation, professionalisation, personnel movement, mergers, and acquisitions. They are recorded in a collective memory that is often coherent but is sometimes jumbled, that often endures but is sometime lost. (pg. 76)

Ingram and Roberts (1999) described a routine as "a pattern of interactions that represents a **successful** solution to a particular problem" (pg.158). Therefore, these routines are sustained through the years until changes are needed. Hence, these routines or configurations could be treated as heritable just like the genetic information that an organism has in its DNA. Furthermore, as the organisation develops, it will have "inherited" resources and management experiences. Future orientation is governed by the resources accumulated and the expertise that is possessed by management. There is a direct connection between the various kinds of activities which an organisation can undertake and the development of the ideas, experience and knowledge of its managers. These fundamentally affect the perspective and functioning of the organisation. At the same time, some routines may arise from external sources such as competitors or consultants.

Winter (1990) also suggested that organisations may be modelled as collections of routines. With the routine as a unit of selection in the evolutionary process. Therefore scholars who study the adoption and desertion of organisational routines could develop an account that does not rely on an organisational inertia assumption, but one which focuses on routines, organisational founding and failures.

The next section will investigate using an evolutionary concept how routines could be "passed" from one organisation to another.

5.2.3 Evolutionary Processes

In Section 5.1.1 presented above, there is a discussion of the three pre-conditions for natural selection to occur. Social scientists have applied these to the study of social systems. As developed by Campbell (1969), the natural selection model for organisations identifies three processes: *variation*, *selection* and *retention* that underpin the evolution of organisations. This concept has been further developed by researchers such as Pfeffer (1982) and Aldrich (1999). Aldrich (1999) added a fourth process, the *struggle* for resource, in an effort to make the theory complete. To explain these processes Table 5.3 is presented.

5.2.3.1 Variation

For the environment to select differentially among organisational forms, there must be some variation in the forms. Aldrich (1999) claimed that any kind of change is a *variation*, and the evolutionary process can begin with variations which may be *intentional* or *blind*. In other words, variation can be planned or unplanned by management in the organisation.

Variation is said to be *intentional* when the organisation attempts to find ways to resolve problems or exploit opportunities it faces. Within organisations, there may be formal programs of experimentation and imitation, such as research and development. Such programs are intentionally created to promote innovative activities that can change the current routine of an organisation to a better functioning or more effective working style. Another source of intentional variation is said to be the incentives provided for innovative employees. Working groups can be created deliberately within the organisation to intensify internal competition and thus promote better functioning. The working groups are then appraised and rewarded when better innovations are created. Consultants hired from outside the organisations can also introduce new managerial practice such as total quality management (TQM), just in time (JIT) and complexity science into the organisation.

Blind variation as cited by Aldrich (1999), occurs independently of environmental or selection pressures. This can include trial and error learning, luck, imitation, mistakes, misunderstanding, surprises, idle curiosity and so forth. It can also take the form of new knowledge or experienced introduced into the organisation by newly recruited employees.

5.2.3.2 Selection

Once variation has occurred, either blindly or intentionally, the new organisational routines are selected according to how well they enable the organisation to acquire resources in a competitive environment. Selection is said to occur *internally* or *externally* (Aldrich, 1999). *Internal* selection criteria are set through the operation of promotion, incentive systems, imitation, internal diffusion, etc. or any activities that are controllable within the organisations. These selections may or may not enhance the organisation's ability to survive. It is possible for new routines to be selected even though they do not conform to existing practices. On the other hand, organisations may link its promotion or incentive systems to out-dated criteria. This will promote old routines against new routines as managers will be more prompt to use established routines. Such measures will reduce the introduction of new routines. *External* selection criteria are set through the operation of market forces, competitive pressures, the logic of internal organisational structuring, and other factors usually beyond the control of individual organisations. Organisations with maladapted variations in technology, managerial incompetence, misunderstood customers' needs, etc. are less likely to acquire competitive resources and are therefore more inclined to failure. As a result, successful or surviving organisations will have comparable and similar characters which are absent in failing organisations.

5.2.3.3 Retention

Retention is said to occur when selected variations are *retained*, *copied* or *imitated*, so that the selected activities are repeated on future occasions or the selected structures appear again in future generations. Retention can occur at two levels, the *organisational* and the *industrial* level. Organisational retention can occur through the industrialisation and documentation of successful routines, and through existing personnel passing on knowledge about routines to new personnel.

Industrial level retention can take place through spreading new routines from one organisation to another. This can happen through personal contacts, or thorough observers, such as academics or consultants publishing successful new technologies or management skills.

5.2.3.4 Struggle

Struggle occurs because the resources provided by an environment are not unlimited. The scarcity of resources fuels the selection process faced by the organisation. In new industries, the leading organisations have ample gain and enjoy fast growth. As the population in the industry grows, the resources become more limited, and as a result failure rates increase. This can cause the population to stagnate or decline.

Evolutionary Process	Definition	Example
Variation	Change from current routines and competencies: change in organisation forms	
	Intentional: occurs when people actively attempt to generate alternatives and seek solutions to problem	Within organisation: problemistic search Between organisations: founding of new organisation by outsiders to an industry
	Blind: occurs independently of environmental or selection pressures	Mistakes, misunderstandings, surprises, and idle curiosity
Selection	Differential elimination of certain types of variations	
	External selection: forces external to an organisation that affect its routines and competencies	Market forces, competitive pressures, and conformity to institutionalised norms
	Internal selection: forces internal to an organisation that affect its routines and competencies	Pressures toward stability and homogeneity, and the persistence of past selection criteria that are no longer relevant in a new environment
Retention	Selected variations are preserved, duplicated, or otherwise reproduced	Within organisations: specialisation and standardisation of roles that limit discretion Between organisations: institutionalisation of practices in cultural beliefs and values
Struggle	Contest to obtain scarce resources because their supply is limited	Struggle over capital or legitimacy

Source: Aldrich (1999), pg. 22

Table 5.3 Evolutionary Process for Organisations

In summary, if we consider the four evolutionary processes they can be used to help explain how organisations come to exist in different forms serving different environments or niches. In order to exploit environments, organisations must be able to adapt appropriately and to do so they must continuously seek to change routines. For example, in the late 1960s, when the Japanese developed the concept of quality as a competitive weapon, it drastically changed the routines and expectations of mass production organisations, because if an organisation did not have this quality concept in its strategy or plan, it would struggle to survive. Another example, is if a firm perceived that another firm had a better performance due to better products or cheaper production costs, then this firm would observe and try to learn the appropriate routines. Such imitation or adoption of best practices is openly supported by government sources such as the UK Department of Trade and Industry and the UK Engineering Physical Sciences Research Council or consultancy agents.

The spreading of routines is not confined to just manufacturing processes, but also includes the structure of organisations. In a study of organisation structure by Fligstein (1985) the top 100 US companies during 1919 to 1979 were analysed. The study revalued that in 1929, only 1.5 percent of the companies had multidivisional form structure, but sixty years later 80 per cent used this structure. Multidivisional form structure had been developed to deal with the growing complexity of large firms (Williamson, 1975) and General Motors was a successful example of this structure that encouraged imitation by others (Rumelt, 1986). Also Malerba and Orsenigo (1996) observed that organisations do have a imitative strategy which aims to keep pace with competitors by examining what they are doing.

From these two examples, organisations could be viewed as a species consisting of routines, that similar to the genotypes found in organisms. Also, such routines can be inherited from the previous organisational forms or configurations. The consequence is that management have the freedom or choice to change an organisation's routine from one to another as an organisation adjusts to its changing environment.

In summary, organisational changes are driven by the introduction and diffusion of different ways of operating, i.e. routines. Organisations are able to constantly search for better configurations in order to enhance survival and growth. Routines, whether they be incremental or radical, are similar to mutations, as they introduce new ways of working and functioning into existing organisational structures. While searching encourages both variety, and imitation, competition dissipates the differences so that an organisation's progress depends on how well it can find a suitable routine. This is similar to the natural world where speciation and selection are the driving forces behind the changing patterns of plant and animal life.

5.2.4 Definition of Organisational Fitness

With Section 5.2.3 presenting a theory by which to view organisational evolution, this section builds on that theory (variation, selection, retention and struggle) and presents a definition for organisational fitness.

Recent studies such as Nelson and Winter (1982) and Beinhocker (1999) related organisational fitness to company profits, but did not explain the rationale for linking fitness to such a measurement. Also, the notion that a firm with high fitness is able to yield good profits, while a firm yielding good profit is not necessary fit, was not addressed. This is a common problem for companies that focus solely on profit as a performance indicator. Such short-term views can obscure long term survival agendas and thus limit an organisation's fitness. Moreover, companies may often forfeit long-term survivability or healthy growth in order to generate short-term profit. Therefore, a definition of organisational fitness cannot be based entirely on profit yields, although there is a strong correlation.

Miller (1992) distinguished between two types of fitness, the *environmental fit* and the *internal fit*. The former required organisations to match their structures and processes to their external settings, whereas the latter focuses on the development of organisational structures that would work well internally. Both were seen as central to organisational fitness, yet they could conflict with one another. For instance actions to increase or even to maintain environmental fit could prevent or decrease the internal fit. This issue characterises attempts to define organisational fitness and is similar to that of biological fitness attempts, where species on one hand need to adapt to the environment, while seeking to develop an internal advantage. Therefore organisational fitness (like biological fitness) must be multidimensional in nature, and hence the measurement should also be multidimensional. Therefore, organisational fitness could be viewed as a joint function of internal and external fitness in the short term. With these combinations, organisational fitness in the long term will provide: growth, survival, control over the external environment and energetic storage such as profits.

Nelson and Winter (1982) suggest that the adaptive search that included innovation and imitation could be used to increase the performance of organisation. Miles and Snow (1990) agreed that under some circumstances, it was possible for the organisation to survive with a poor strategy. However, the aim of organisations is not merely to be in the market in the short term, but in the long term as well. Unless organisations change their strategies, they could be forced out of the market and end up in liquidation. Therefore, organisations have to constantly search for better routines in order to achieve a balance between survival and growth. But what type of routines will constitute to this purpose?

Noting that managers use a number of short-term indicators for long-term survival, Gibson et al. (1994) listed five criteria that they used to represent such indicators (Table 5.4). The criteria for these indicators may differ from one study to another as we have discussed in Section 5.2.1. However, the primary objective of this citation, similar to Gibson et al.'s intention, is that these five criteria are just a representation of all organisational routines.

Criteria	Definition
Production	Ability to produce the quantity of goods and services the environment demands
Quality	As the ability to meet customer and client expectations for product performance and service provision, with the source of measures and judgements of quality coming form customers and clients.
Efficiency	The ratio of outputs to inputs in the entire process cycle.
Flexibility	The ability to shift resources from activity to activity to produce new and different products and services in response to customer demand.
Satisfaction	This refers to employees' sense of well-being about their jobs and roles in the organisation.

Table 5.4 Five short-term Criteria for Organisation

With the above commentary on the relationship between fitness, profits and survivability, coupled with the notions of internal fit and environmental fit, this thesis proposes the following definition of organisational fitness as:

> *The ability for organisations to increase their survivability and long-term growth within its interacting environment, through inheriting, imitating and searching short-term routines or criteria (measurable or immeasurable) such as production, quality, efficiency, flexibility, satisfaction etc.* (See Figure 5.3)

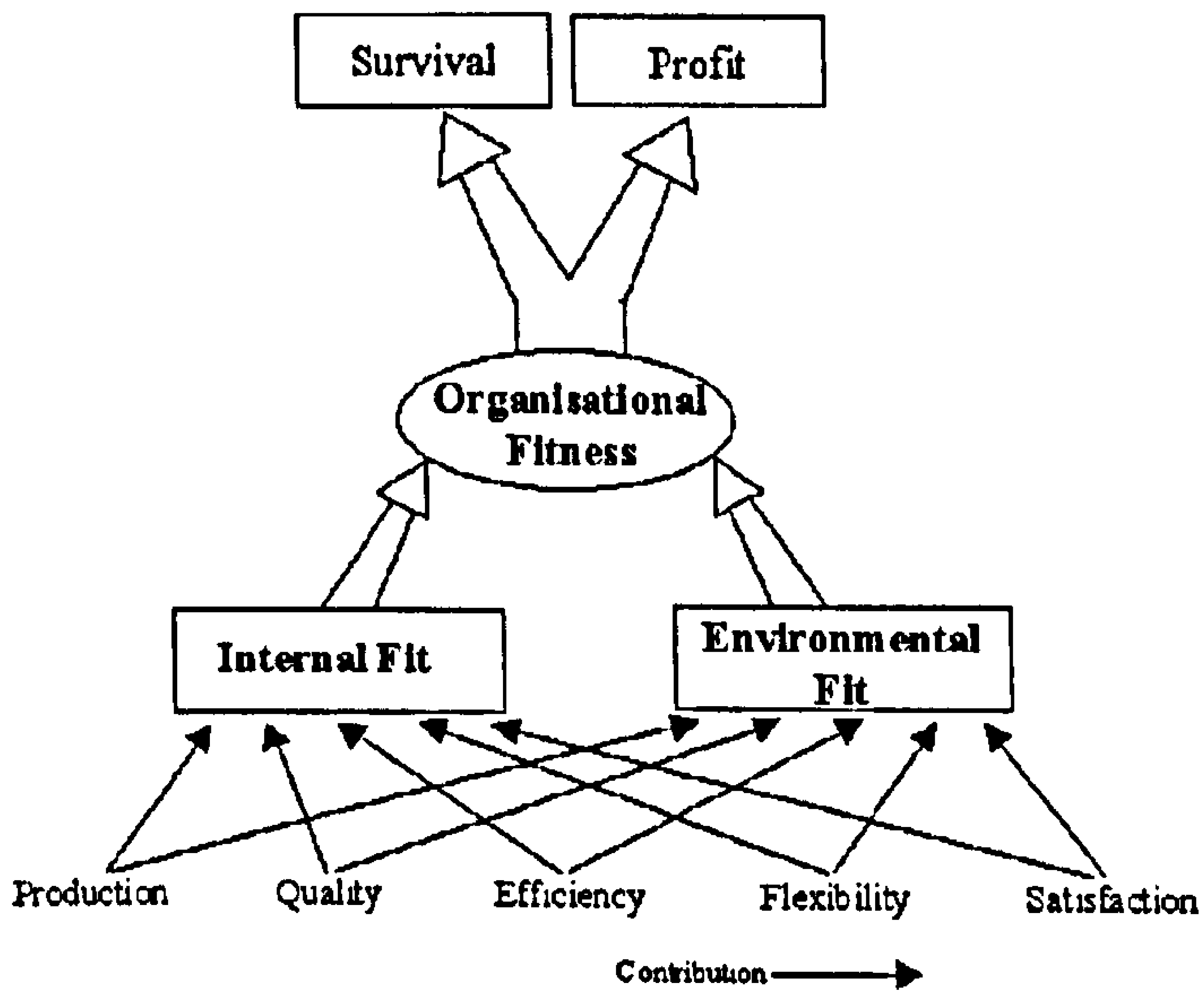


Figure 5.3 Definition of Organisational Fitness

It is important to note that from the above definition, an organisation should have the competence and willingness to face changes through "imitating and searching" better routines. These two abilities can be summed up as the organisation's *adaptability*. Adaptability, which has been presented in Table 5.1, is the degree to which an organism (or organisation in this case) can remain or become adapted to a wide range of environments by physiological or genetic means. Hence there is a tangible link between organisational fitness and adaptability.

5.3 Manufacturing Fitness

The final objective of this chapter is to provide an initial evaluation and definition for *manufacturing fitness*. This initial definition is then developed and discussed further in Chapter 6. As per the discussion given in Section 5.2, this final section evaluates the existence of manufacturing organisations by defining their operational purpose. This then followed by a discussion on how manufacturing strategy supports these purposes and thus the basis of a definition of manufacturing fitness.

5.3.1 Purpose of Manufacturing Organisations

Wild (1995) reported that there are four principal system functions that distinguish one industrial organisation from another. They are:

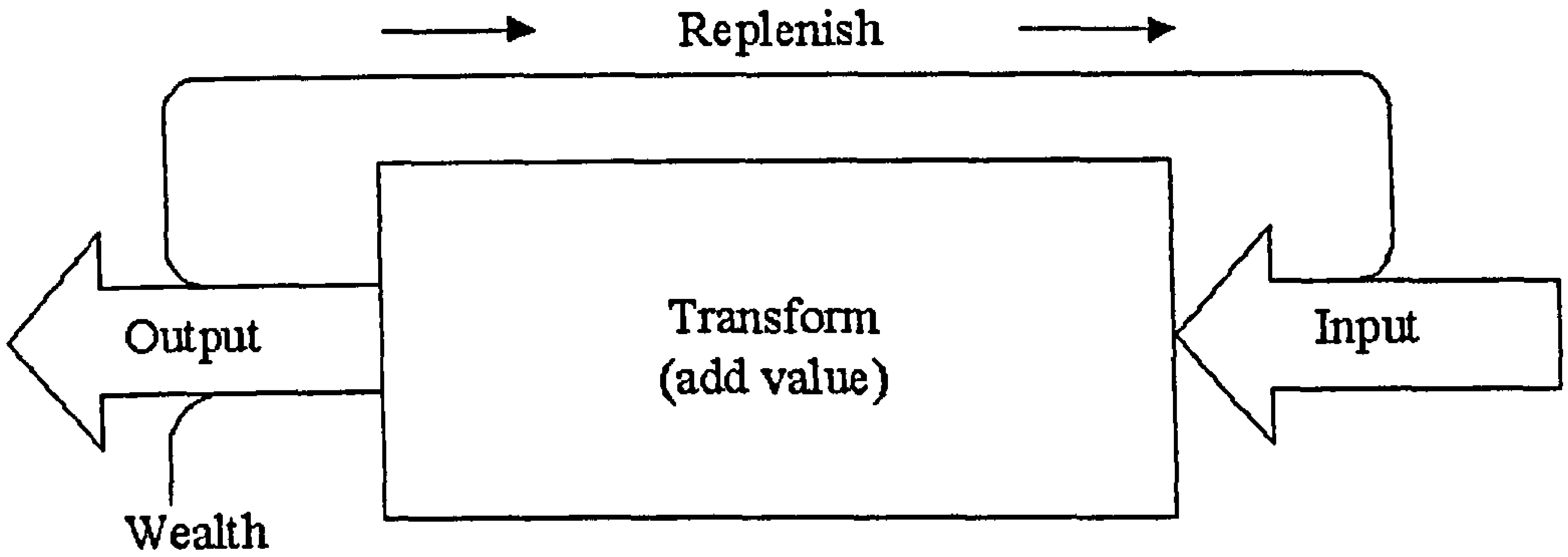
1) manufacturing : where something is physically created;
2) transportation : where a customer or customers' possession is moved from place to place;
3) supply: where ownership of goods is changed; and
4) service : where the treatment or accommodation of something or someone is provided.

Wild also noted that it was possible for all four systems to be found within one organisation, as these functions form the sub-systems found in many organisations. For example, a typical manufacturing organisation is not simply concerned with making products, it also must provide after sales service and logistics to supply the product. Therefore, when an organisation is described as being a "manufacturing organisation", this simply refers to its primary organisation activity, the activity that traditionally provided the added value to customers (the term manufacturing can be taken to mean the conversion of raw material in into products, which can be sold (Bolton, 1983)). Furthermore, the principal common characteristic of manufacturing organisations is that something is physically created (Wild, 1995). In other words, the output consists of goods that differ physically from the material input to the system. "Manufacturing" therefore provides physical transformations, or a change in form of resource. According to Bolton (1983), manufacturing can thus occur at three levels:

1) Altering the raw material from an initial state into a coarse product that can be used to produce follow on items, for example, iron ore to steel sheet, crude oil to petroleum.
2) Converting material into components or parts, for example, steel into ball bearing, castings, and forgings.
3) Assembling parts and components into finished products or goods, for example, car assemble from a variety of components.

All manufacturing organisations acquire inputs such as materials, components, machines, services and labour. These resources are then organised to produce outputs for sale in the open market. During this conversion of inputs to saleable products, costs incurred by the organisation rise in relation to the level of resource input and the level of transformation activity. The revenues collected from the sale of products must be greater than the cost incurred, in other words, the financial exchange must provide a surplus of income over expenditure. These surpluses will then be used to purchase further inputs that replace the resources used up during the transformation process. The remaining surplus, if any, will be returned to the owners who possess the facilities. This cycle of resource acquisition, transformation and outputs will mean that manufacturing organisations must depend on other groups and organisations both in the input-acquisition and the output-disposal phase of the cycle.

From the above discussion, it can be seen that manufacturing is a process of adding value, that is central to wealth creation in an industrialised society. The global performance measurements are immediate profit and long term competitiveness (Williams, 1994). Lupton (1986) even suggests that "manufacturing industry exists to create wealth" (pg. 190). See Figure 5.4.



Source: Lupton (1986), pg. 190

Figure 5.4 Manufacturing Firm as Wealth Creator

5.3.2 Manufacturing Strategy

Kim and Lee (1993) described manufacturing strategy as a process that "*supports corporate objectives by providing manufacturing objectives including: costs, quality, dependability and flexibility to offer a competitive advantage and focus on a consistent pattern of decision making within key manufacturing resource categories*". Thus, the objective of manufacturing strategy is to create 'operationally significant performance measures' in which the competitive dimensions comprise cost, quality, dependability and flexibility.

The following will briefly explain these manufacturing capabilities.

Quality importance. Different definitions of quality are often seen by different functions such as engineering, marketing, and manufacturing. Garvin (1987), produced a framework that integrated the different perspectives. This framework identified eight dimensions: *performance*, *features*, *reliability*, *conformance*, *durability*, *serviceability*, *aesthetics*, and *perceived quality*. Traditional manufacturing wisdom has tended to focus primarily on quality control in the form of conformance. However, each other form of quality listed, could be seen as providing a basis for competition.

Delivery time importance. On-time delivery is the ability of a manufacturer to deliver products to customers according to a promised schedule. Companies with this capability are able to compete on the basis of reliable delivery times. Also, the delivery speed is a key requirement to win customer orders.

Flexibility importance. Flexibility, like quality can have many different meanings. Some managers associate flexibility with the ability to change from one product to another, with negligible cost penalties. Another view of flexibility, is the ability to alter production volumes to satisfy market demand, again with negligible cost penalties. Gerwin (1993) developed seven dimensions of flexibility. These dimensions are *product mix, volume, changeover, modification, re-routing, material* and *sequencing.*

Cost importance. All manufacturers are concerned with this capability, but most do not compete solely or even primarily on this basis. However, this capability is particularly important in commodity-like products such as steel, paper and chemicals, where there is little differentiation among products. Products produced by mature industries also tend to compete on this basis primarily. Through this capability, manufacturing organisations can leverage an increase in market share or enhance profitability.

With this introduction and brief explanation of manufacturing strategy, coupled with the previous discussions on organisational fitness, this thesis proposes a definition and preliminary model for manufacturing fitness:

> *The ability for manufacturing organisations to increase their survivability and competitiveness in the manufacturing environment, through inheriting, imitating and searching manufacturing strategy (or routines) such as quality, delivery, flexibility, and cost.* (See Figure 5.5)

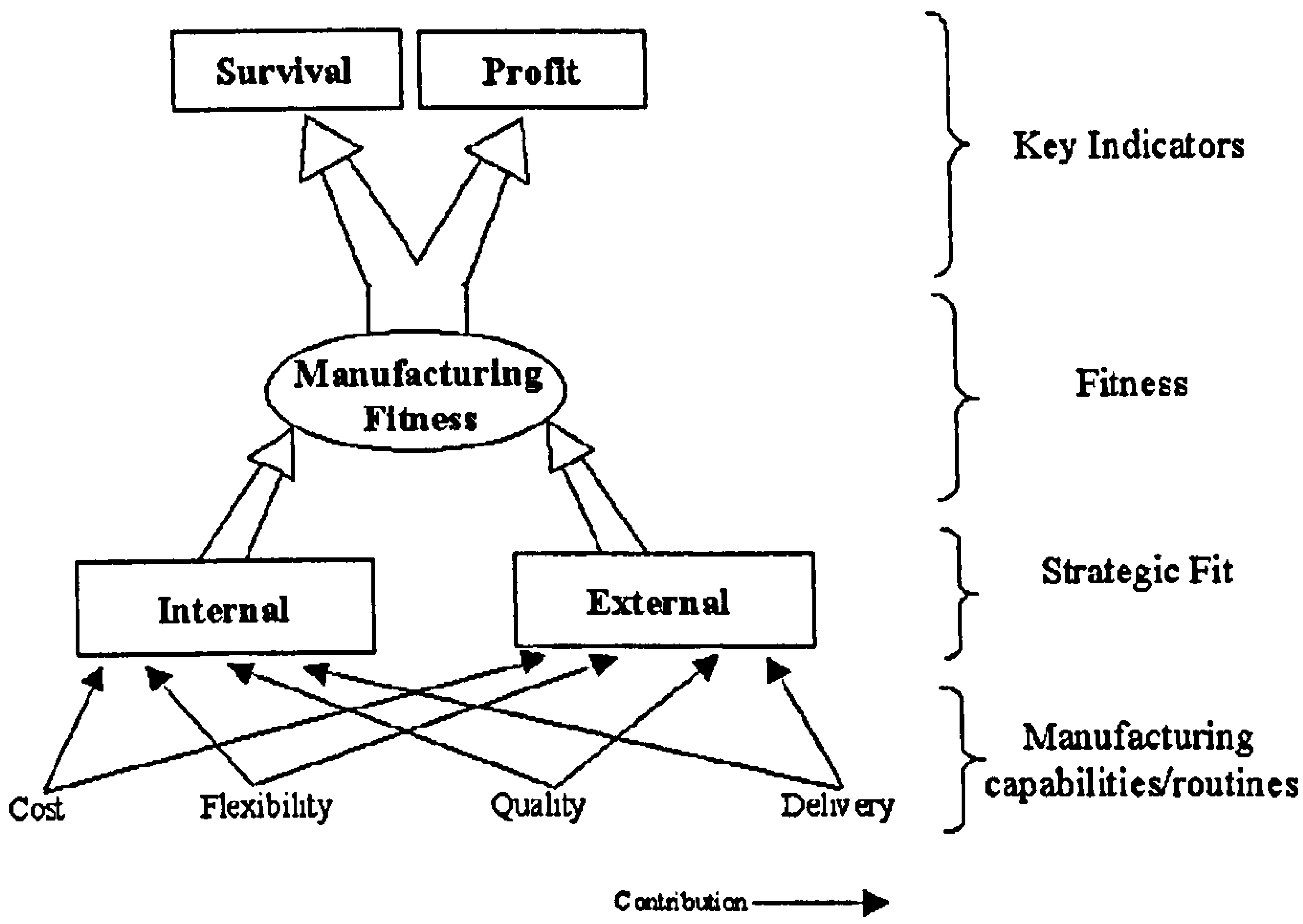


Figure 5.5 Manufacturing Fitness

With this definition of manufacturing fitness, it is assumed that the performance of the manufacturing organisation depends on the manufacturing capabilities alone, up to a proportionality constant. Although this is not always true, it does provide a good starting point to compare the fitness of different manufacturing strategies used by different organisations. With this definition and the fitness landscape method it is possible to explore the combinations of manufacturing capabilities that could exist and the relative performance of each. This would address a need noted by Swink and Way (1995) who state that more studies on the combinations of manufacturing capabilities are needed to comprehensively understand manufacturing strategy.

5.4 Conclusion

The objective of this chapter was to provide a usable definition of fitness, first in a biological context, then in an organisational context and lastly in a manufacturing context. From the biological review, it was found that fitness can be defined in various ways according to the different fields of study. This is neither a positive or negative point as this indicates that fitness could suit different fields of application. With this point in mind, the task of defining organisational fitness in accordance with the knowledge that organisations and manufacturing organisations are complex adaptive systems, appeared to be possible.

By reviewing organisational existence and effectiveness from an evolutionary perspective (variation, selection, retention and struggle), a definition of organisational fitness was presented. Prior to this study, organisational fitness had not been formally defined and thus the attempt presented in this thesis is novel and pioneering. The difficulties associated with producing such a definition are linked to the multidimensional and multi-objective nature of organisations. For example, different departments can have different and in some cases conflicting operating objectives. The definition of organisational fitness created by this thesis attempts to address this problem and provide an overall definition for the organisation, from organisational level and open-system perspective.

Finally, by developing this fitness into a manufacturing context, that considers the key components of manufacturing strategy, it was possible to create a preliminary definition of manufacturing fitness. The following chapter will explain this definition of fitness and its defining manufacturing characteristics in detail.

Chapter 6. Manufacturing Strategy Review

In Chapter 5, manufacturing fitness was introduced, defined and related to manufacturing strategy. To understand and develop this definition of manufacturing fitness, manufacturing strategy must be examined in greater detail. The first section of this chapter contains an overview of how manufacturing strategy research has evolved. The role of manufacturing capabilities is also discussed in terms of the trade-off concept and its opposing theory: the compatibility or cumulative model. This discussion concludes with a literature review of several empirical studies that have sought to validate the two models. The second section of this chapter discusses in further detail the characteristics of four manufacturing capabilities. These four capabilities, quality, cost, flexibility and delivery form the basic elements to describe manufacturing competitive. The third section reviews the role of performance measurements used in manufacturing environment. To implement the manufacturing capabilities effectively, organisation needs some measurements to assess these programs. Hence this section discusses some performance measurements available in manufacturing environment. This section also highlights the importance of the correct performance measurements. Furthermore, this section cites three available tools that facilitate managers in the selection of appropriate performance measurements. The chapter concludes by presenting a fitness landscape model that integrates the findings of this chapter (in terms of strategy, capability and performance measurements) with the findings of Chapter 5 that introduces a model and definition of manufacturing fitness.

6.1 Introduction to Manufacturing Strategy

It was approximately three decades ago that Skinner (1969) emphasised the need for manufacturing strategy to be in line with corporate strategy. He proposed that a company should define its manufacturing tasks in order to support the corporate strategy. This was termed the "missing link" of corporate strategy. In Chapter 5, this thesis cited the following definition for manufacturing strategy by Kim and Lee (1993): it "*supports corporate objectives providing manufacturing objectives* *including costs, quality, dependability and flexibility to offer a competitive advantage and focus on a consistent pattern of decision making within key manufacturing resource categories*". With this definition, manufacturing strategy can be clustered into finer manufacturing objectives such as cost, quality, flexibility, etc. Furthermore, manufacturing strategy is also viewed as the effective use of manufacturing capabilities to achieve business and corporate goals i.e. the correct use of manufacturing capabilities will produce effects that will appear in the financial results.

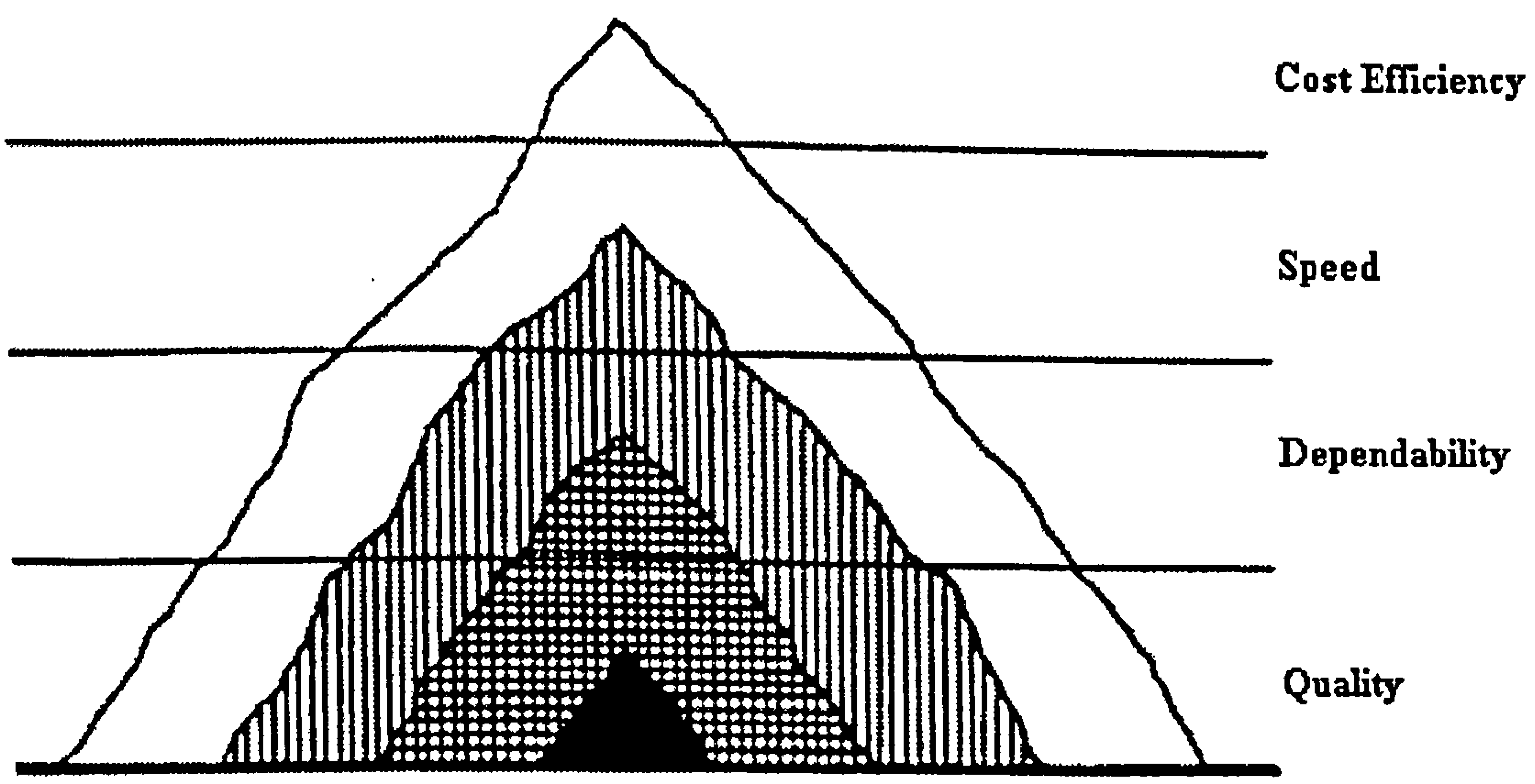
6.1.1 Concept of Trade-off

Five years after promoting the importance of manufacturing strategy, Skinner (1974) suggested that production facilities could not perform well for all tasks or capabilities, and that organisations should focus on a selection of tasks only. This implied some form of **trade-off** was unavoidable and was the basis of the *focused factory* or *focused manufacturing strategies*. In other words, Skinner believed that in order to achieve a high level of performance on one capability, one had to sacrifice the performance of one or more of the other capabilities i.e. the concept of trade-off. This concept also has biological relevance as Cody (1966) reasoned that organisms have a limited amount of energy, and that they could allocate it to reproduction, competition or avoidance of predators, i.e., there are trade-offs among the three options. Just like organisms, companies only have limited resources, which means that they should concentrate and develop certain advantages to compete and serve certain markets or niches.

This trade-off concept inspired many studies including Hill (1993) who developed the "order-winners" and "order-qualifiers" from the manufacturing capabilities. He observed that qualifying criteria simply maintains a company's position to compete in the market, but does not contribute to successfully winning orders. From these criteria, manufacturing companies designed and developed strategies to compete in the market, and the concept of "trade-off" was implicit. Recently Filippini et al. (1998) described the trade-off issue as being the achievement of high values in one type of performance, resulting in low values in others.

6.1.2 No Trade-off - Compatibility

In recent years, several scholars questioned the validity of the trade-off concept. Nakane (1986) noted that Japanese manufacturers were developing manufacturing competitiveness through the progressive build-up of capabilities; first the capability of quality, then dependability, then cost and lastly flexibility. Based on a similar concept, Ferdows and De Meyer (1990) argued that capabilities are inter-linked with one another and the present of one should not necessarily mean that it should be a trade-off with others, but that it should reinforce other capabilities. Therefore, competencies were considered to be of a sequential and cumulative nature and not independent. The Ferdows and De Meyer paper also gathered evidence from the 1988 European Manufacturing Survey to support their theory and to reject the traditional trade-off model. They proposed a cumulative model, also known as the "sand cone model" (see Figure 6.1). This model suggested that management could improve performance by organising capabilities on top of one another like a sand cone. Their empirical study suggested that the bottom layer is quality, and this layer provides the conditions for further improvement. Once a quality philosophy has been put in place, management are then in a position to achieve manufacturing dependability, this in turn allows management to pursue speed improvements and so on.



Source: Ferdows and De Meyer (1990), pg. 175

Figure 6.1 The Sand Cone Model

In a separate study Miyake et al. (1995) shared the same view about acquiring capabilities and examined companies that had adopted JIT, TQC and TPM practices in Japan. The authors suggested that companies employed a number of policies in order to strengthen their capabilities. Likewise Hall and Nakane (1990) suggested that manufacturers should pursue progress in a step-wise fashion through the capabilities: company-developed culture; quality improvement; dependability; cost reduction; flexibility and then innovation. Correa (1994) suggested that flexibility can influence other capabilities such as quality, dependability, cost and speed and therefore capabilities complement one other. This is in contrast to the trade-off concept, which views **compatibility** as the prospect of achieving good performance in different operations (Filippini et al., 1998).

This cumulative model has motivated studies to gather empirical evidence to validate or revoke this model. Table 6.1 shows the competitive capabilities identified from the studies that took place from 1992 onwards. It is important to note that researchers still do not agree about the two models and that Swink and Hegarty (1998) cautioned that some capabilities identified by the studies did not distinguish between manufacturing capabilities and manufacturing outcomes. In a conceptual study, they cited that the list of manufacturing capabilities: cost, quality, dependability, and flexibility contained both characteristics. The cost construct is an outcome, while flexibility is a means to an end. Therefore, to ratify this issue, they proposed a new set of capabilities grouped in two categories: growth and steady state capabilities. The growth capabilities consist of improvement, innovation and integration, whereas the steady state capabilities are control, acuity, agility and responsiveness. From these capabilities, the manufacturing outcomes are cost, quality, service and time.

	Quality	Cost	Delivery	Flexibility	Depend-ability	Innov-ation	Time	Market Scope
Roth and Miller (1992)[a]	Y	Y	Y	Y				Y
Corbett and Vanwassenhove (1993)	Y	Y					Y	
Neely et al. (1994)[b]	Y	Y		Y			Y	
Sweeney and Szwejczewski (1996)	Y	Y	Y	Y				
Choe et al. (1997)	Y	Y		Y	Y			
Mapes et al. (1997)	Y	Y	Y			Y	Y	
Szwejczewski et al. (1997)			Y					
Noble (1997)	Y	Y	Y	Y	Y	Y		
Boyer (1998)	Y	Y	Y	Y				
Ward et al. (1998)	Y	Y	Y	Y				
Ward and Duray (2000)	Y	Y	Y	Y				

a) Authors used "price" instead of "cost"
b) Although authors used "time" as a capability, it is focused on the "delivery" definition

Table 6.1 Survey of competitive capabilities.

Corbett and Vanwassenhove (1993) also pointed out the importance of distinguishing between internal and external manufacturing capabilities. In their paper, they used the term *competence* to include internal capabilities such as cost, time and quality and *competitiveness* to include external capabilities such as price, place and product (these definitions are developed loosely from the 4 Ps of product) (see Table 6.2). They also noted that some studies did not make a clear distinct between the two measurements and therefore the measurements proposed by those studies tend to be ambiguous and confusing. Also, they proposed that capabilities were not just simple attributes, but complex multi-dimensional concepts. Ward et al. (1998) even developed a scale of measurement for well known manufacturing capabilities such as: quality, cost, flexibility and delivery.

Term	Definition
Competence (internal capabilities)	Cost: the sum of all costs including developing, producing, delivering, servicing, and disposing of product
	Time: include the role of dependability, flexibility and rate of innovation. Therefore this will include all lead-time-related factors, such as average lead-time between receiving an order and delivery of the product, variability of lead time, time to market for new products.
	Quality: all physical aspects of the process and product delivery.
Competitiveness (external capabilities)	Price: sum of financial costs to the customer such as ordering, receiving, using, and disposing of the products.
	Place: everything concerned with delivery of the product, such as location and time of delivery, order adjustment and cancellation conditions, availability of innovative products.
	Product : all properties of the physical product.

Table 6.2 Internal and External Capabilities.

6.1.3 Review of Trade-off and Compatibility

A study by Roth and Miller (1992) was initiated to find the key components of manufacturing capabilities that successful companies had acquired. The authors defined manufacturing strategy as "the pattern of manufacturing choices that are made in the context of corporate goals and objectives". They used the achievement of the business unit goal, as a performance measurement. Companies were classified into two categories: *leaders* and *laggers*. They found that successful companies focus their efforts on a few critical factors in a particular order and that there was no trade-off in capabilities. Also, they proposed that the cumulative model should have an order such as: (i) quality, (ii) delivery, (iii) market scopes, (iv) flexibility and price. They also introduced an additional capability, market scope, that represents a set of value-added activities that exceed the traditional manufacturing boundaries. Furthermore this capability allows companies to capture and indicate how well manufacturing integrates with their customers' requirements and the market needs. Another interesting finding was that their data showed that the quality capability among the leaders and laggers was not significantly different and therefore quality is necessary, but not a sufficient condition for winning orders in the current climate.

Sweeney and Szwejczewski (1996) used a generic classification of sectors differentiated by stock turns and throughput efficiency for 138 firms competing for

1993/94 Best Factory Award. They divided the sample into four strategic manufacturing groups separating the high and low performers. From this study, they found that when the number of products increases (i.e. flexibility increases), the delivery rate decreases. Sweeney and Szwejczewski suggested that this could be due to the increase in complexity of product scheduling and the problems associated with supply chain management. Therefore, they deduced that good delivery was associated with a focused product strategy. Another interesting finding was that when a company introduces more complex processes to accommodate flexibility, the unit cost of the product increases.

Based on a subset of data taken from the 1992 and 1993 Best Factory Awards, Szwejczewski et al. (1997) separated 98 manufacturing plants into three groups based on varying lead times. The delivery performance of the three groups was then compared to see if there were significant differences in the delivery performance. The authors found that manufacturing plants with short lead times achieved significantly better delivery performance than those plants quoting long lead times. This finding contradicted the conventional wisdom that plant managers quoting long lead times had plenty of "slack" to accommodate problems and ensure on time delivery.

Using data from a previous study, Noble (1997) compared and contrasted the manufacturing capabilities of high and low productivity firms. He used labour productivity gains (from one year to another) and relative productivity (the plant's rank in its own industry sector) for 561 firms world-wide as a form of performance measurement to differentiate firms. He found that a large number of firms fell into the median of the productivity measures. The study used the highest 150 firms to represent the high-productivity group and the lowest 150 firms to represent the low-productivity group. He also classified manufacturing capabilities into quality, delivery, cost, dependability, flexibility and innovation. From the analysis, this study revealed that the high-productivity companies tend to have multiple and simultaneous capabilities that focused on quality, dependability and cost.

Using questionnaires for the Best Factory Award, Mapes et al. (1997) tried to determine a correlation between different areas of manufacturing performance which included cost, quality, lead time, delivery and innovation rate in the 782 manufacturing plants. All pairs of performance measure rankings with the exception of one between cost and quality were found to be positively correlated. However, the authors were unable to explain the lack of correlation between cost and quality using the percentage of customer returns against the output as a measurement of quality consistency. Nevertheless, their findings showed there was no trade-off. Furthermore, there was evidence that good performance in one measurement seemed to lead to good performance in other measurements. Another finding by Mapes et al. (1997) confirmed the benefit of having a strategy that focused on certain capabilities. They noted that plants with a narrow product range tend to perform better in most measures compared to those plants with a wide product range. Also, the wider the product range the slower the rate of new product introduction.

In an empirical study of manufacturing competitive priorities (quality, delivery, cost and flexibility) and company investment in structure and infrastructure, Boyer (1998) discovered that investment in design-based advanced manufacturing technologies (AMTs) such as computer aided design and engineering or process planning (CAD, CAE or CAPP) were not associated with the four priorities. Boyer explained that this could be because design AMTs were common in manufacturing and had become standard for most organisations. On the other hand, if a company did not possess AMTs, it was likely to suffer a reduction in customer orders. Another concern that Boyer raised was that there were indications that companies simply did not know how to increase flexibility, although this capability was considered to be strategically important. A summary of several other studies is presented in Table 6.3.

Authors	Data and source	Findings
Roth and Miller (1992)	Data from 180 executives in 1988 Manufacturing Futures Project (MFP). Divide the companies into "leaders" and "laggers" based on the degree of achieving business unit goals.	1) Leaders showed superior manufacturing capabilities than laggers. 2) Leaders also possess varying degree of strength in each performance criteria. 3) Findings support cumulative theory than trade-off theory.
Sweeney and Szwejczewski (1996)	Grouping the 138 manufacturing plants into 4 sectors by stockturns and throughput efficiency. Firms competing for 1993 and 1994 Best Factory Award.	1) Evident that unit cost of production increases with higher complexity of manufacturing operations 2) Evident that on-time delivery is associated with focused product strategy and with the flexibility of operations.
Szwejczewski et al. (1997)	Dividing 98 manufacturing plants into three groups by varying lead times. Plants competing for Management Today Best Factory Awards for the year 1992 and 1993.	1) Reject the trade-off between lead times and delivery performance.
Noble (1997)	Comparing 150 firms with high productivity and 150 firms with low productivity from the 561 data. Uses data from a prior study.	2) High-productivity firms are more likely to address multiple capabilities simultaneously than low-productivity firms. 3) High productivity firms showed capabilities on quality, dependability and cost.
Mapes et al. (1997)	782 questionnaires from the UK Best Factory Award.	1) No trade-off. 2) Good performance on one measurement seemed to lead to good performance on other measurements. 3) Plants with narrow product range outperform plants with a wide product range. 4) The latter has a slower rate of inducing new products.
Boyer (1998)	Surveyed 112 manufacturing plants in 1994 and 1996 to measure the co-relationship between manufacturing strategy made in 1994 and investment made 2 years later.	1) Investment in designed based advanced manufacturing technologies (CAD, CAPP, CAE) are not with any of the four manufacturing priorities. 2) No investment is made for flexibility priority for all the plants.
Ward and Duray (2000)	Surveyed 101 firms.	1) Differentiation strategies are more effective in dynamic environment. 2) There is a strong link between quality and business performance. 3) Poor performers will fit poorly with model proposed. 4) Manufacturing strategies are linked to good business performance.

Table 6.3 Summary of key strategy surveys.

6.1.4 Discussion on Manufacturing Capabilities

From the review given in the previous section it is noted that there are various terms coined for describing manufacturing capabilities including: *competitive priorities* (for example see, Hayes and Wheelwright, 1984; Boyer, 1998), *order winner and qualifiers* (see Hill, 1994), and *competitive capabilities* (see Roth and Miller, 1992) . To help clarify the definition of capability an explanation is presented: *Capabilities* are an organisation's capacity to deploy its own resources (financial, technological, physical and human assets) (Lefebvre and Lefebvre, 1998). Thus, manufacturing capabilities are considered to be stocks of strategic assets which are accumulated through a pattern of investments over time and cannot be easily imitated or acquired by trade, nor can good substitutes be found (Ward et al., 1996). Manufacturing capability refers to the realised, as opposed to an intended strategy.

In Chapter 5, manufacturing fitness was defined as "the ability for a manufacturing organisation to increase its survivability and competitiveness in the manufacturing environment, through inheriting, imitating and searching manufacturing strategy". Central to this definition is the ability to understand the capabilities that influence manufacturing fitness. What capabilities should we seek then? The main criterion to select these capabilities could be the existence of these capabilities in successful manufacturing organisation strategy-makers. The awareness and hence application of these capabilities among these manufacturing organisations would then be traceable in their daily operation routines. These realised capabilities would then be linked to the organisations success and achievement. Furthermore, these selected manufacturing capabilities should be well-known among operation analysts so that cross-references could be done to validate the linkage of these manufacturing capabilities and their fitness performance. Lastly, with these selected manufacturing capabilities, further validations could be done in other studies. Looking back, Table 6.1 has listed the manufacturing capabilities identified in the literature review. From this table, it is obvious that the four manufacturing capabilities: quality, cost, flexibility and delivery were most commonly analysed by scholars. These four capabilities were also found to be the highest ranking manufacturing objectives in manufacturing executives in the 1980s (Schroeder et al., 1986). Furthermore, many studies (for example, Ferdows and De Meyer, 1990; Leong et al., 1990; Garvin, 1992; Ward et al., 1996; Ward et al., 1998) also agreed that these four capabilities form the basic components that describe manufacturing competitiveness. Therefore, they provide a valued starting point by which to express manufacturing fitness:

$$\text{Manufacturing fitness} = f(\text{Quality, Cost, Flexibility, Delivery})$$

However, this research recognised that this list of manufacturing capabilities is not exhaustive. The next section discusses in the detail each of the four selected manufacturing capabilities introduced above. These include: quality; cost; flexibility and delivery.

6.2 Break Down Of Manufacturing Strategy

In order to begin determining a function for manufacturing fitness it is important to specify in detail the different manufacturing capabilities. Garvin (1993) disassembles manufacturing strategy into detailed parts and develops an aggregated strategy as follows.

6.2.1 Quality

Quality has been a management tool since the 1980s, when the western world was shaken by Japanese products that quickly captured market share. At that time, quality was a vague concept that was difficult to implement or even understand. Since then it has been studied and experimented with in many ways, so as to improve quality of operations, product and service. Techniques, such as total quality management (TQM) and just-in-time (JIT) underpinned this quality revolution.

Quality in a manufacturing and product context can be described as follows:

Performance. This refers to a product's primary operating characteristics. For example a television is differentiated primarily on the basis of sound quality, picture clarity, colour etc.

Features. These are secondary characteristics of product or service. For the television set, it could be the presence of a built-in digital decoder, or a picture freeze frame function.

Reliability. This is the probability that a product or service will fail within a specified period of time. The measures can be the mean time to first failure, the mean time to failures, and failure per unit time.

Conformance. This is the degree to which a product or service meets pre-established standards. For example, engineering standards such as product hardness, material finish, etc.

Durability. This is the amount of use a product can sustain before it physically deteriorates or until repair is no longer economical. For example, the number of hours of use that a light bulb can provide.

Serviceability. This is the speed, courtesy, and competency of repair. For example, the frequency with which repairs need to be repeated because they were performed incorrectly the first time.

Aesthetics. This is the look, feel, taste, smell, and sound of a product or service. For example, the styling and appearance of a television.

Perceived Quality. This final dimension of quality as underpinned by the above dimensions and is the resultant perception of quality. This helps organisations develop a brand and company image that is synonymous with quality.

Hill (1993) had observed that seven of the eight dimensions of quality (except conformance) could be related to the design function and that only conformance related to manufacturing. Although this is true, there is no doubt that there is an increasing trend for manufacturing companies to move away from merely focusing on "making", towards a knowledge rich task of design in order to provide added value.

6.2.2 Cost

Cost capability is the ability to minimise the total cost of production (inclusive of labour, materials, and operation costs) through efficient operations, process technology, and/or scale economies (Markland et al., 1998). Therefore, doing things cheaply involves aiming to get the right mix of resources and facilities to provide good value products and service at low cost. Cost efficiency can be achieved through increased capacity utilisation, reduced overheads, multi-purpose equipment and facilities, and higher productivity. Cost also can be reduced through such means as wise selection of suppliers, shipping methods, employment of processing technology, material handling method, appropriate work forces sizes and skills, good inventory management, product design, equipment maintenance and replacement.

Slack (1991) noted that cost in production could be affected by three groupings: *volume*, *variety* and *variation* of products.

Volume of products

In its simplest form, the significance of volume is mainly a matter of higher throughput - spreading the fixed costs of production over a greater number of products produced. Hence the unit cost would be reduced. This long-term volume-cost effect is also referred to as "economies of scale". As capital costs increase at a slower rate than capacity, there are economy gains in producing large volumes of product. This feature is a driver for almost all products, but it has particular importance for commodity-like products such as steel, paper and chemicals where there is little differentiation among the products.

Variety of products

High production costs are often related to an excessive variety of products (Alford et al., 2000). This variety related cost is a result of high parts variety, process variety and routing variety. Capital is needed to invest in sophisticated equipment and complicated control systems to handle and monitor the complex process. Excessive product variety will also mean increased overheads, which come in the form of complex purchase effects, inventory, coordination etc. The overhead consequences of variety are widespread and can be very significant. Hence, more effects are needed to focus on this issue. From the sale-variety relationship, Mather (1988) observed that 80 per cent of sales revenue is usually represented by 20 per cent of the product lines. This relationship is often known as the 80:20 curve or the Pareto curve.

Variation of products

Variation refers to the degree of demand fluctuation for products over a period of time. Manufacturers long for a steady product demand, but have to face uncertainty and cycles. This variation will have cost effects depending on how management deal with the situation. One strategy is to adjust the output to reflect the actual product demand. This however will mean increased labour cost (overtime pay or hiring new workers) when demand is high, or at low product demand, under-utilised labour and equipment. The other strategy is to level the inconstancy of demand by means of inventory. This however will mean more capital cost, storage space and inventory procedures are needed.

It is commonly known in manufacturing that unit cost can be reduced as experience about the production situation is gained. These improvements are achieved by various sources such as improved production methods and tools, improved product design, standardisation, improved material utilisation, reduction of system inventories, improved plant layout and product flow, economies of scales etc. All these are bracketed as *organisation learning* (Buffa and Sarin, 1987). When attempting to reduce costs many manufacturing managers do not focus on the largest area of cost. Instead, they concentrate on cutting direct labour costs, which often account for only 10 per cent of the total cost of the product. Up to 80 per cent of the cost can be related to the initial cost and maintenance cost (Hill, 1993). This traditional emphasis on cost reduction has led many managers to equate direct labour to productivity.

Cost as stated in the above discussion would refer to the level of finances consumed by the operations. Since profitability is the residue between selling price and cost, thus by reducing cost, the selling prices of the products can be reduced or the profit of the organisation can be increased. The cost capability has an obvious and direct correlation with the ability to increase market share or enhance profitability. In the latter case, cost efficiency can help an organisation to achieve competitive advantage by not passing savings directly to the customers in terms of lower prices. This decision could enable organisations to have higher retained earnings and hence fund strategically on other activities such as research and development (R&D), programs to develop or design better products and processes. Hence this capability has been an important issue for manufacturers.

6.2.3 Flexibility

Traditionally when manufacturing companies were established many aspired for economies of scale with high volumes of throughput. This standard approach to mass production was successful in satisfying a newly emerging mass market, but once consumers had become saturated with mass produced products different drivers such as quality and choice began to influence purchasing decisions. To offer choice and variety required manufacturing organisations to regularly reconfigure operations. The ability to do this was termed *flexibility*. Flexibility had not been taken seriously until the early 1980s and was previously viewed as a trade-off against efficiency.

Sethi and Sethi (1990) define flexibility in manufacturing as "*being able to reconfigure manufacturing resources so as to produce efficiently different products of acceptable quality*". They proposed this definition after identifying and reviewing some 50 different definitions of the word. In this context, the term *resources* includes equipment and labour. Ruef (1997) observed that generalists (manufacturers with no specific product focus) have greater flexibility as they can decide which core technologies or products to divest and which new or even potential, unrelated products to produce. While specialists develop core competencies in a given area which can hamper adaptive strategic positioning, the greater the specialist equipment a company utilises, the greater is the tendency for that company to sacrifice flexibility. The cost of investing in such equipment will drive the company to rely and focus on a narrow band of products for that equipment, so as to ensure a good rate of return on the investment.

A dangerous myth concerning flexibility is that by implementing high levels of computer integration into a company, management can achieve high levels of manufacturing flexibility. There is evidence from Upton (1995) that paper plants with high levels of computer integration had a smaller product range compared to those companies with low levels of computer integration.

To summarise flexibility in a manufacturing context the following account is given:

Product flexibility

- New products. The speed with which new products are created, designed, manufactured and introduced.
- Customisation. The ability to design a product to a particular customer's specification.
- Modifications. The ability to modify existing products for special needs.

Volume flexibility

- Uncertain Forecasts. The ability to respond to sudden changes in the volume of a particular product as required by the market.
- Ramp-ups. The speed with which new manufacturing processes can go from small volumes to full-scale production.

Process flexibility

- Mix flexibility. The ability to manufacture a variety of products, over a short time span, without modifying existing facilities.
- Changeover flexibility. The ability to adjust smoothly to changes in product mix over the long term.
- Re-routing flexibility. The degree to which the fabrication or assembly sequence can be modified if machinery or equipment is out of order.
- Material or factor flexibility. The ability to accommodate variations in raw material and raw material substitutions.
- Sequencing flexibility. The ability to rearrange the order in which parts are fed into the manufacturing process, because parts and raw material deliveries are uncertain.

Primrose and Verter (1996) suggest that *flexibility just happens to be a convenient word which helps describe the fact that manufacturing facilities must be capable of dealing with change and uncertainty.* Therefore, managers are not required to define or measure flexibility (if they were able to do so) because this does not necessarily improve the quality of their decisions. On the other hand, researchers such as Gerwin (1993) and Upton (1995) focus on trying to measure this capability using metrics such as changeover time, lead times, and process and product range. Therefore, it is possible to operationalised flexibility by introducing new products, new production processes, product varieties, product features, and R&D effort.

6.2.4 Delivery

This capability is the degree to which a plant can achieve delivery against a quoted delivery date. The orthodox wisdom for manufacturers was therefore to quote a long lead-time which contained plenty of time in order to reduce the risk of not achieving the delivery date. Garvin (1993) suggested that there are more dimensions to this capability including order management, transportation and installation management, and warehouse management. In addition to the infinite tactical components, this capability includes development of the infrastructure required for managing channel business rules, ordering rules, delivered inventories, and delivery quality. The following is a summary of these elements:

Accuracy. This is whether the correct items were delivered, and in the correct quantity.

Completeness. This is whether the shipments were filled completely the first time, or did certain items have to be backordered.

Dependability. This is whether the product was delivered for the agreed date.

Availability. This is the probability that the items will be in stock at the time of order.

Speed. This is the elapsed time between order placement and the time that the product reaches the customer.

Information Accessibility. This is the degree to which real-time information is available about a shipment.

Quality. This is the condition of the product after shipment.

Ease of ordering. This includes issues such order preparation assistance, electronic ordering or immediate notification that items are out of stock.

Ordering flexibility. This is when there are limits on the minimum permitted size of orders and the assortment of items in a single order.

Shipment flexibility. This is the ability to re-route delivery to accommodate special circumstances.

Ease of return. This is the willingness to absorb the cost of returning and processing a product return.

This section discussed and decomposed the various components that are embraced in the four manufacturing capabilities. The main purpose of this section is to increase the awareness of these manufacturing components among manufacturing managers. By examining these components in detail, it is anticipated that manufacturing managers will then have the knowledge to recognise or in some cases, implement these manufacturing capabilities further when necessary. However, to implement these capabilities successfully, one has to use the right tactics. The next section will discuss the performance measurements used in manufacturing.

6.3 Performance Measurement used in Manufacturing

This section discusses the role of performance measurement in manufacturing. Performance measurement is more than just a passive means for assessing what has already happened, but also most importantly, to motivate particular behaviours and hence promote future success. By using the wrong measurements to assess a continuing improvement program, the verdict can be misleading. This may lead to the early termination of improvement programs and the obstruction of improvement effects at production level. In recent times, accounting systems have become the primary means by which organisations track and assess performance. This section begins by discussing the drawbacks of this traditional measurement.

6.3.1 Traditional Measurements

The cost management systems that were developed in the early 1900s are still being used extensively today even though there have been strong efforts to introduce more appropriate and manufacturing friendly performance measurement systems (Martin, 1997). The limitations of a traditional cost accounting system have been widely discussed, for example see Scapens (1991) and Kaplan and Atkinson (1998). Several approaches for improving these systems and in some cases replacing them have been proposed by these papers. Alternative approaches include Activity-Based Costing (ABC) (see Wiersema, 1995) and Total Quality Accounting (see Woods, 1994).

Traditional performance measures are based on traditional accounting systems, such as return on investment (ROI), return on assets (ROA), return on sales (ROS), purchase price variances, sales per employee, profit per unit production, and productivity. The limitations for these traditional measures has been cited by authors such as (Kaplan and Norton, 1992; Ghalayini et al., 1997; Martin, 1997) and revolve around the issue that they focus on controlling and reducing direct labour costs. However, as mentioned in Section 6.2.2, direct labour cost can be minor compare to the other costs. Kumpe and Bolwijn (1988) noted that labour costs for a consumer electronic product can constitute only 5% of the total costs, whereas material costs can be up to 70%, with the remaining 25% tied to indirect costs. Also, with improvements in technology, the time to manufacture and assemble products has been reduced tremendously and therefore such measurements do not capture the necessary improvement needed. Secondly, traditional measurements are often out of date as it is costly to keep monitoring and maintaining a log of such costs. Thirdly, traditional measurements are often in conflict with newly developed technologies and manufacturing philosophies such as JIT, OPT and TQM.

6.3.2 Multi-dimensional Measurements

Organisations operate in multiple domains and may only perform well in a limited number of them. This multidimensional view of performance, implies that different patterns or configurations of relationships between organisational performance and its determinants will emerge (Ostroff and Schmitt, 1993). Since manufacturing companies are a sub-category or specific type of organisation, studies that attempt to find recurring patterns of attributes in this type often lead to valuable insights about what should be considered for a multidimensional views.

The Department of Trade and Industry (1994) defined the **competitiveness** of a firm as "*the ability to produce the right goods and services of the right quality, at the right price, at the right time. It means meeting customers' needs more efficiently and more effectively than other firms*" (pg. 9). The next section of this thesis examines the meaning of *efficiency* and *effectiveness* for manufacturing organisations.

6.3.3 Efficiency and Effectiveness

Efficiency is the measure of the relationship of outputs to inputs often expressed as a ratio. Some authors refer to it as "doing the thing right" (Chow et al., 1994; Hill, 1993). Efficiency measures may be expressed in terms of actual expenditure of resources as compared to expected expenditure of resources, or may be expressed as the expenditure of resources for a given output. Typical efficiency measures include:

Unit cost per output. This is defined as the relationship of total resource expenditure for a given output. To obtain this measurement, output identifications such as managerial accounting techniques are requested to assign direct and indirect costs to that output.

Work Measurement. This is the ratio of a predetermined standard time for a given task compared to the labour hours consumed.

Labour Productivity. This is the ratio of final outputs produced to labour input (hours or full time equivalents) consumed compared to a base period.

Cycle Time. This is the amount of time elapsed between the initiation of the demand for a product or service and the actual receipt by the user of the output. Cycle time includes the work process time and the wait time between work processes. Cycle time is an important manufacturing measurement as it captures the time interval that resources are committed to producing a final product. It includes the actual work process time and the wait time between actual work. The longer the cycle time, the more resources will be tied up in inventory.

Effectiveness is defined as the measure of output conformance to specified characteristics. Some authors refer to this as "doing the right thing" (Chow et al., 1994; Hill, 1993). Indicators of effectiveness include:

Quantity. This is the number of outputs produced, or level/access to services (e.g., inventory fill rate, number of repairs carried out, etc). Effectiveness measures associated with quantity are sometimes expressed as the ratio of actual to planned work.

Timeliness. This is the number of outputs that meet scheduled completion dates and products/services that are supplied within an objective time standard.

Quality. This is the outputs that conform to objective use requirements for an output. For instance, in supply operations the item shipped must meet customer requirements in terms of being the right part received on time. Other measures include the acceptable number of defects in the product received by the customer, or the number of complaints received, or the cost of rework.

Customer Satisfaction. This is a measure of conformance to customer expectations. Typical direct measures can include customer satisfaction surveys, and complaint rates. Indirect measures include internal error rates and rework costs.

From the above discussion it is clear that manufacturing companies face various drivers, objectives and metrics. With this multitude of interests manufacturing organisations are constantly assessed by a variety of parties, each with a preferred type of measurement. For example, investors, company directors, customers, suppliers and employees all have different views on the performance, efficiency and effectiveness of organisations.

6.3.4 Importance of Performance Measurements

During the 1980s, many companies committed large resources to implement operational improvement programs such as total quality management (TQM), just-in-time(JIT), manufacturing resource planning (MRPII) and flexible manufacturing system (FMS). However, many companies did not adopt appropriate performance measurement systems despite the change in operational activity and management. This caused a mismatch between operations and performance measurement. Viswanadham and Raghavan (1997) noted that performance measurement is important for monitoring, control and management, but Neely et al. (1994) surveyed 301 UK small businesses and found that some companies, especially those with a focus on price, did not match their strategies with the performance system used. Such mismatches restricted a company's ability to achieve the required results. In a study by Schaffer and Thomson (1992), it was observed that the benefits of "total quality" could not be achieved after several companies committed large amounts of money for training employees. These companies believed that their employees could accumulate the knowledge through training, but were not able to utilise the knowledge appropriately. Schaffer and Thomson argued that managers should concentrate on *results-driven* improvement programs that focus on achieving specific and measurable operational improvements instead of *activities-centred* programs. With a result-based approach, managers could build skills accordingly and gain the support of their employees for future changes.

The above discussion, shows that companies may be willing to invest in improvement programs, but without an appropriate performance measurement system to justify such programs, this can lead to disillusionment of future improvement programs. Williams et al. (1995) reported that companies in the textile industry (a mature industry) should focus on quality assurance programs as it can lead to significant improvements in performance, when compared to programs that focus on planning and control systems or innovative manufacturing processes. Therefore, it is important for all levels of an organisation, especially senior management to understand the selection of appropriate performance measures and how these can influence the strategic direction of the company. The next section reviews the tools that available to manufacturing mangers to assist them in the selection of performance measures.

6.3.5 Manufacturing Performance Measurements Tools

The performance measurement questionnaire (PMQ) developed by Dixon et al. (1990) helped managers to identify the improvement needs of their companies. The authors claimed that the results of this PMQ enabled organisations to identify competitive priorities and performance factors. These could then be used to determine the extent to which the existing performance measures support improvements. Also, they established an agenda for performance measure improvements. The advantage of this, is that it provided a mechanism for identifying the improvement areas of the company and their associated performance measures. However, PMQ does have some limitations as it is not designed for the collecting the data required to construct a measurement system. Also, it also does not take into account the process of continuous improvement (Ghalayini et al., 1997).

Another tool called, the "balanced scorecard" was developed by Kaplan and Norton (1992) to examine four different measurements (financial perspective, customer perspective, innovation and learning perspective, and internal business perspective) simultaneously. The aim of this tool is to help managers have a clearer and better understanding of strategy. This tool uses goals set by top management based on the four different measurement perspectives. In each area, specific measures are identified to achieve each goal. The performance indicators reflect and help emphasise the linkages between the performance areas. However, since it was designed for the top managers to focus on strategy, it can require additional activities to filter these strategic indicators to a level appropriate for operational performance.

Ghalayini et al. (1997) developed an integrated dynamic performance measurement system (IDPMS) that integrates three areas of a company: management, process improvement teams, and factory shop floor. This tool presents the interactions between the different areas of success, performance measurement, and performance indicators. Also, it integrates financial measures with operational measures by specifying distinctive areas of success.

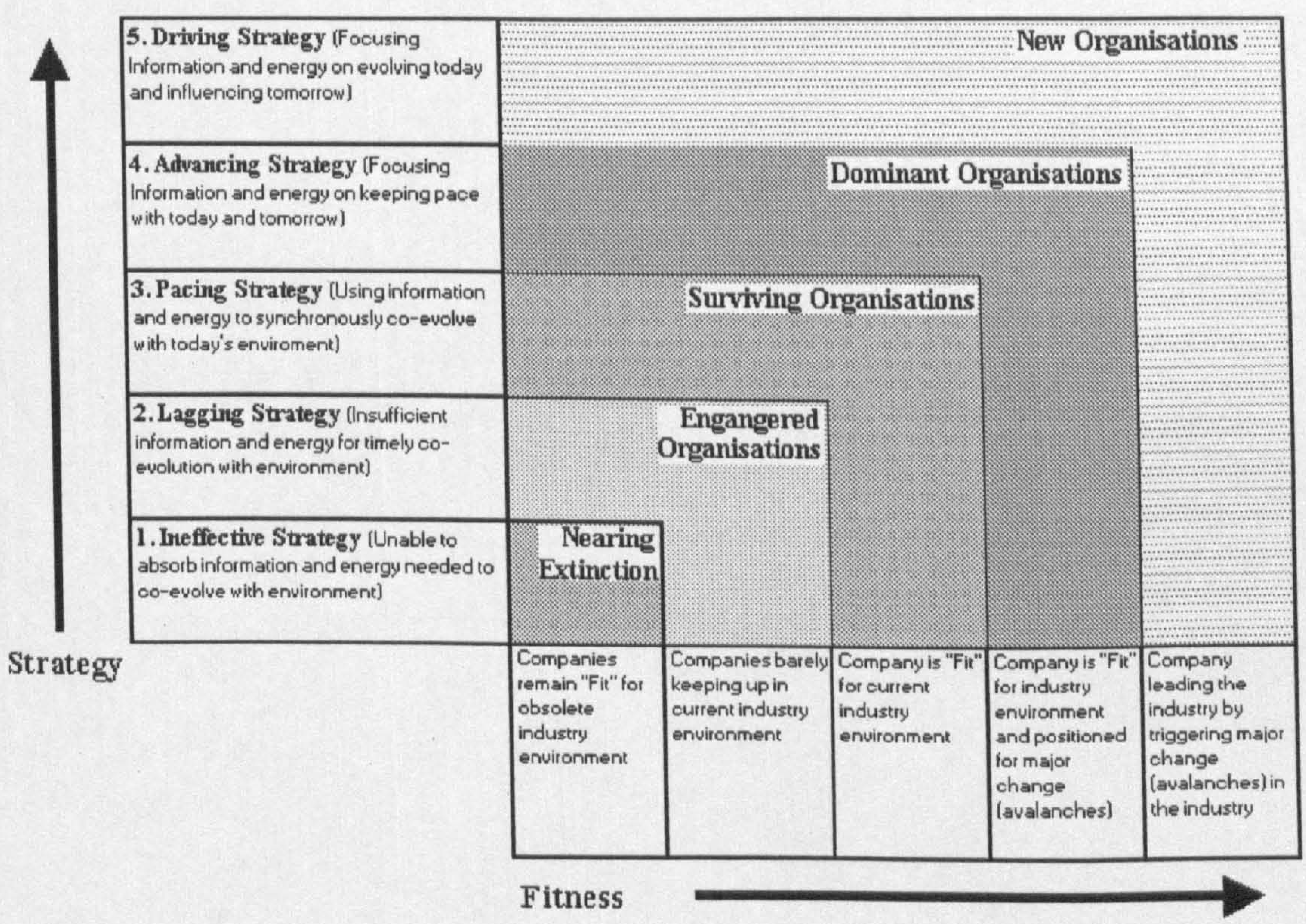
6.3.6 Discussion on Performance Measurements

It is common for strategy to change its form as a result of actions (Dixon et al., 1990). In order for strategies and their supporting actions to be successful, it is necessary to measure the performance of these actions and their contribution towards strategic outcomes. When performance measurements are chosen, the type of measurement should vary according to the structural level within an organisation. Financial measurements have a greater emphasis as the hierarchy level rises. As one moves down the hierarchy, the emphasis shifts from financial to operational indicators (e.g. scrap rates, lead-times and cycle times). To summarise, performance measures should aim to achieve corporate objectives, even at the lower levels of an organisation.

It is common for researchers to combine several measurements, in other words, multi-dimensional measurements to evaluate a company (Filippini et al., 1998). For example Sarkis (1997) defined performance based on multi-factor productivity measures; Samson and Terziovski (1999) used customer satisfaction, employee morale, productivity, quality of output and delivery performance to determine the success of firm. However, Filippini et al. (1998) criticised the ambiguity of each study defining and developing its own set of performance metrics. Nevertheless, it is not the aim of this thesis to point out the different aspects of manufacturing measurements, but to highlight the effect and importance of using a combination of measurements. Goldratt and Cox (1993) demonstrated this in their publication the *The Goal*, which stated that the optimisation of local section can result in the sub-optimisation of the firm as a whole. Therefore, with this foresight, the measurement for manufacturing fitness will have to be multi-dimensional in order to capture the whole organisation performance more appropriately.

6.4 Model For Manufacturing Fitness

As discussed in the last section of Chapter 5, manufacturing organisations are established to create wealth for owners and therefore financial measurements are important. However, if a short-term financial measurement is used to grade the firm performance solely, there is a risk that the firm will align itself solely for short-run profits and hence create long-run problems that hinder its survivability. Also, firms that rely heavily on conventional measures such as financial performance, often have little or no warning of further problems or failures (Hitt, 1988). McMaster (1996) observed that there could be big winners for a short period of time, but these winners will not last for a period of extended time. Therefore, survival is a function of fitness with the environment now and in the future. The challenge for a manufacturing company is to continually develop both the abilities to adapt and to influence the competitive environment. How well organisations can master this skill will determine whether they will dominate the industry, just survive or go out of existence. See Figure 6.2.



Adopted from Kelly and Allison (1999), pg. 22

Figure 6.2 Stage of Fitness for Strategy

To further develop the cumulative capability concept suggested by Ferdows and De Meyer (1990), this research proposes an initial model of manufacturing fitness (see Figure 6.3) and suggests that capabilities can be correlated as well as cumulative. It is known that by improving quality, the cost of production can come down significantly. There are many studies on the relationship between these two capabilities. Furthermore, these two capabilities have formed the basic foundation for manufacturing strategy. It would be impossible to market any product without these two capabilities and no sensible manufacturing company would sell their products with poor quality and high prices and expects their customers to return. However, manufacturing managers in a broad senses agree that achieving low cost and high quality are no longer enough to guarantee success or even to win orders and therefore other capabilities such as flexibility and delivery have been considered.

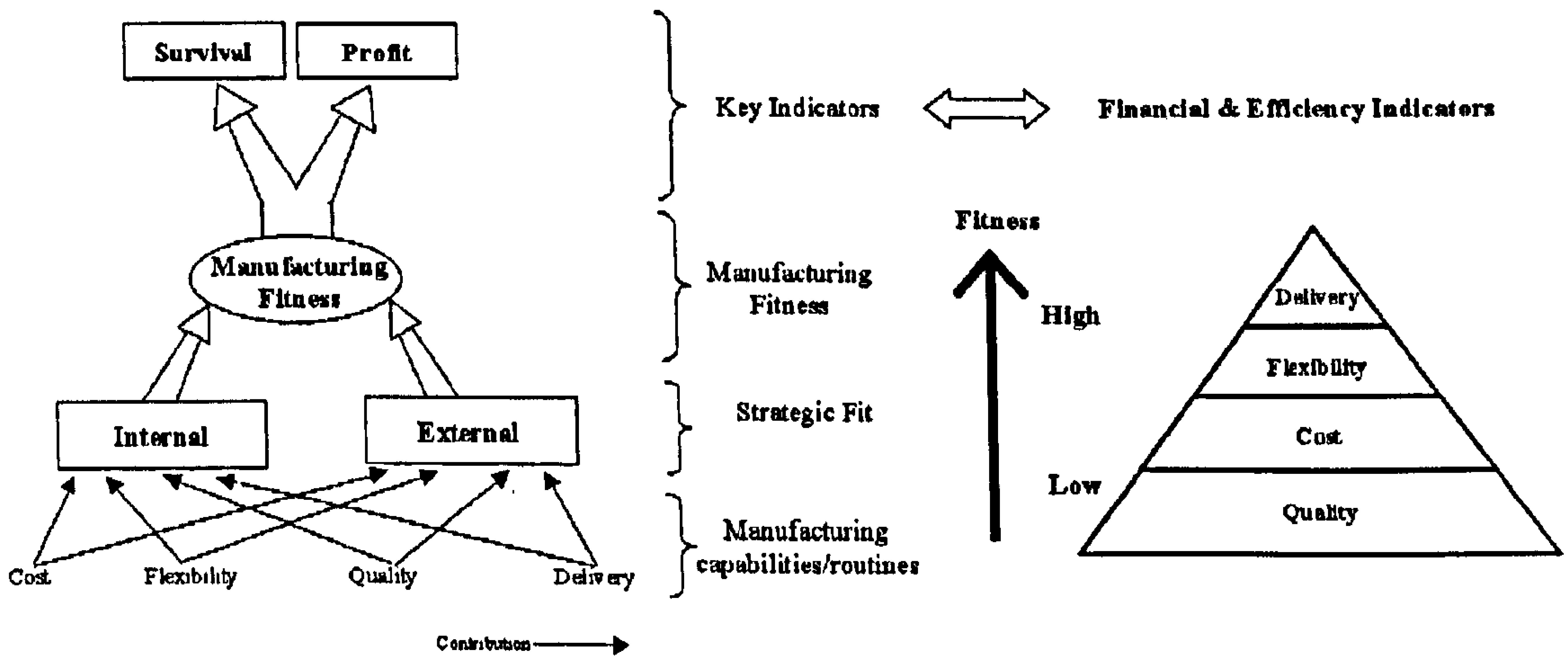


Figure 6.3 Pyramid of manufacturing fitness

However, further knowledge about the manufacturing environment must be carried out to validate the model and to relate it to manufacturing fitness. The next chapter provides this commentary.

6.5 Conclusion

This chapter evaluated the role of manufacturing strategy in manufacturing organisations. As discussed, manufacturing strategy can increase an organisation's competitiveness and hence increase its chance of survival. To achieve this competitiveness, manufacturing strategy can be further broken up into more specific action groups, known as manufacturing capabilities. For decades, researchers have been studying these capabilities in detail. Although the grouping of these manufacturing capabilities can be vague at time, the most commonly analysed capabilities are *quality*, *flexibility*, *cost* and *delivery*, and these are the focus in this research. Although agreeing that these manufacturing capabilities will increase an organisation's competitiveness, operational analysts have developed two contradictory models - *trade off* and *cumulative*. Analysts that support the trade off model argue that manufacturing organisations can not deploy a range of capabilities due to limited resources and hence need to concentrate on a core capability. Whilst the cumulative model supporters have a discordant view and provide evidence that some organisations can perform better with a combination of these manufacturing capabilities. The opposing concepts and arguments for these two models are at the heart of the fitness model concept, because fitness acknowledges and represents both issues.

Lastly, this chapter reviewed the role of performance measures in manufacturing. Appropriate performance measures not only indicate the real progress associated with the implementation of an improvement program, but they also prevent the early termination of beneficial programs. By citing several performance measure tools, this chapter showed how certain manufacturing capabilities should be exploited by manufacturing managers. Furthermore, this review of performance measurement also highlighted the importance and necessity of using several different indicators to describe the real condition of manufacturing organisations. This discussion also paved the way for the selection of manufacturing fitness indicators in the next chapter.

From the discussion in Section 6.1.3 there is evidence that manufacturing capabilities are not totally defined by trade-offs, but nor are they completely compatible and complementary (Sweeney and Szwejczewski, 1996). Therefore, it could be useful for manufacturing companies to have a tool such as a manufacturing capabilities map that would help them understand, navigate and realise the benefits of implementing different configurations of manufacturing capabilities. The map in this context refers to a diagram that represents the relative positions of these different manufacturing capabilities which constitute in the manufacturing competitiveness landscape. This mapping process will be discussed in the coming chapter.

Chapter 7. Methodology and Results

7.1 Introduction

Chapter 6 evaluated manufacturing strategy, capabilities and performance measurement with a view to selecting capabilities that would be central to a model of manufacturing fitness. Four manufacturing capabilities were selected: quality, cost, flexibility and delivery. This chapter concluded by relating these four capabilities to the fitness definition and model that was proposed in Chapter 6.

This chapter consists of two parts. The first part, which has three sub-sections, deals with the formulation and calculation of manufacturing fitness. The first sub-section divides manufacturing capabilities into the two categories of existence or non-existence to distinguish between success or failure of implementation of the manufacturing capabilities. The second sub-section combines different financial performances into a unity fitness measurement that could be used to compare the fitness of different organisations. The third sub-section relates this measure of manufacturing fitness with the manufacturing capabilities that an organisation possesses.

While the first part of this chapter explains manufacturing fitness in abstract, the second part seeks to demonstrate and validate these calculations with the data gathered from the Mx2000 survey. It features the calculated manufacturing fitness for the surveyed manufacturing organisations. It then presents the fitness of different combinations of manufacturing capabilities. It also states several observations from these combinations. Lastly, a method for representing fitness and the corresponding manufacturing capabilities as a map (to show the relative position of the four manufacturing capabilities) is proposed and constructed.

7.2 Formulation of Manufacturing Fitness

It is assumed that the relative performance of I manufacturing organisations whose overall manufacturing capabilities (M) are recorded in J different capabilities and performance measures (P) are recorded in K different categories. Thus, for ith organisation, the manufacturing capabilities could be recorded as:

$$\mathbf{M}_i = (\mathrm{M}_{i,1}, \mathrm{M}_{i,2}, \mathrm{M}_{i,3}, \ldots, \mathrm{M}_{i,J}) \quad \text{------} \quad \textbf{Equation 7-1}$$

and the corresponding performance would be represented by:

$$\mathbf{P}_i = (\mathrm{P}_{i,1}, \mathrm{P}_{i,2}, \mathrm{P}_{i,3}, \ldots, \mathrm{P}_{i,K}) \quad \text{-------} \quad \textbf{Equation 7-2}$$

where $i = 1, 2, \ldots, I$

7.2.1 Classifying Manufacturing Capabilities

It is not uncommon for analysts to divide the study samples into several, or more commonly two, distinctive groups so as to contrast the groupings. For example, Nelson and Winter (1982) developed a two-technology evolutionary model by dividing the known techniques as either "old" or "new". Similarly, Porter (1980) developed a model consisting of two generic strategies - "cost leadership" and "differentiation". Roth and Miller (1992) contrasted the factors that contribute to the success of organisations by classifying their surveyed organisations into "leaders" and "laggers". These scholars, with their relatively simple classifications, were then able to develop their theories or models further. As a result, more insight could be gathered through these simple groupings. Motivated by this type of analysis, the manufacturing fitness calculation proposed by this thesis will determine and classify the manufacturing capability deployment into two categories - either "*existence*" or "*non-existence*". To explain this concept briefly, organisations that fully understand and implement certain manufacturing capabilities will show the realised capabilities through their daily and strategic operations. Hence, Hannan and Freeman (1977) suggested that the generic structure (such as routines or manufacturing capabilities) can be found in organisations by examining their mode of operating. In other words, by analysing an organisation's operations, one can deduce whether the manufacturing capability is in *existence* or *non-existence* in the organisation's routine. To determine the existence of a manufacturing capability, a *partition value*, $\overline{M}_j$ will be used. This partition value can be assigned for example, as the mean value of the *j*th term of the manufacturing capabilities. Any capability that scores above this partition value will be considered to be in existence; any capability with a score that is below this value, will be considered to be in non-existence.

To summarise, for the *i*th organisation with a *j*th manufacturing capability value, $M_{i,j}$, the *transformed manufacturing capability*, $M^T_{i,j}$ will be 0 if it is below this partition value, whilst it will be 1 if it is higher or equal to the partition value. Therefore $M^T_{i,j}$ can be referred to as

$$M^T_{i,j} = \begin{cases} 0 \text{ if } M_{i,j} < \overline{M}_j \\ 1 \text{ if } M_{i,j} \geq \overline{M}_j \end{cases} \quad \text{------- Equation 7-3}$$

for $i = 1, ..., I$ and $j = 1, ..., J$

For example, if we consider the capability levels of Organisation *A* (cost, quality, flexibility, delivery) we might find a score of (3.6, 5.2, 2.6, 6) for the four manufacturing capabilities. This would then be converted to (1 , 1 , 0, 1) using a 3.5 point partition value. In other words, Organisation *A* has been deploying cost, quality and delivery capabilities and not flexibility in this example.

7.2.2 Fitness Calculation for Manufacturing Organisations.

Let $\mathbf{P}^+$ be the fitness matrix that represents the possible attribute values attainable for a measured performance. This matrix is denoted by:

$$\mathbf{P}^+ = \left(P_1^+, P_2^+, ..., P_K^+\right) = \left(\max\{P_1\}, \max\{P_2\}, ..., \max\{P_K\}\right) \text{-------- Equation 7-4}$$

This matrix then provides the basis to benchmark organisations. The new value will be known as the *primary fitness*. The primary fitness of *k*th terms, $PF_{i,k}$ can be obtained as followed:

$$PF_{i,k} = \frac{P_{i,k}}{P_k^+} \text{ -------- } \textbf{Equation 7-5}$$

Let w_k be the predetermined normalised weighting of the *k*th performance where $0 \leq w_k \leq 1$ and also:

$$\sum_{k=1}^{K} w_k = 1 \text{ ------- } \textbf{Equation 7-6}$$

With this the fitness of $Organiation_i$, F_i^{ave} will be the aggregate of all the its primary fitness contributions.

$$F_i^{ave} = \sum_{k=1}^{K} w_k \, PF_{i,k} \text{ ------- } \textbf{Equation 7-7}$$

If all the weightings, w_k are equally weighted, then the Equation 7-7 will indicate that the *mean fitness* of $Organiation_i$, F_i^{ave} will be the average of all its primary fitness contributions.

$$F_i^{ave} = \frac{1}{K}\sum_{k=1}^{K} PF_{i,k} \text{ ------- } \textbf{Equation 7-8}$$

Thus, the model is a generalisation of the NK model as stated in Equation 4-1 in Chapter 4.

At this stage, every organisation will be assigned a value that reflects its fitness based on the aggregation calculated. In order to calculate the *relative* performance of any organisation, organisations will be bench-marked against the fittest value, which is symbolised by F_i^{ave+}. Hence the *relative fitness* of *i*th organisation, F_i^* will be determined by:

$$F_i^* = \frac{F_i^{ave}}{F_i^{ave+}} \text{ ------- } \textbf{Equation 7-9}$$

7.2.3 Fitness Calculation for Manufacturing Capabilities

The primary interest of the measurement of biological fitness is not to investigate the evolutionary path of organisms, but mainly to know the degree of success in individual that possesses a certain gene (Williams, 1992). It is assumed that the gene that has the best chances of survival in any given environment, tends to be the one that is best for the organism as a whole. The reasoning behind this assumption is that for any organism that survives many generations, it will have genes that resist threats to its existence. As threats emerge and the organism successfully resists, then these successive bouts of resistance will benefit the whole genome by promoting the organism's survivability. By examining the genes of organisms with good levels of survivability, one can identify those genes that are common to organisms with high levels of survivability. This interest of pinning down the success factors is not confined to biology, as it also occurs in sociology studies. For example, a recent study conducted by Roth and Miller (1992) established the linkages between manufacturing success and business success. By classifying organisations into either "leaders" or "laggers" based on the fulfilment of business success, Roth and Miller observed that organisations with good business performance would tend to have an excellent range of manufacturing capabilities. On the other hand, organisations with poor business results were incompetent in their manufacturing capabilities.

Using this notion of isolating genes that are central to survivability, it is possible to identify the individual characteristics of a manufacturing capability and the corresponding fitness. This would enable the comparison of different fitness values between manufacturing capabilities. With this supposition, those manufacturing capabilities that are commonly found in organisations that have a long track record of success, will be central to the concept of fitness. It is assumed that the fitness of a manufacturing organisation depends on the manufacturing capability traits alone, up to a proportionality constant. Although this is not always true as the success of an organisation depends other attributes such as marketing, design, economic demands, etc. it does provide a good starting point to compare the fitness of individual manufacturing capabilities.

For example, if Organisation *A* has quality and flexibility capabilities and is assigned a manufacturing fitness of 0.37, and Organisation *B* has a fitness value of 0.51 based on quality, delivery and cost capabilities, and Organisation *C* has a fitness value of 0.25 based only on delivery, then the consolidated fitness for the quality capability is 0.44 (the average of 0.37 (Organisation *A*) and 0.51 (Organisation *B*)) and for the cost capability it would be 0.51 as only Organisation *B* has this capability.

7.3 Results

Table 7.1 shows the scoring of the four manufacturing capabilities using the Mx2000 performance scores for 13 manufacturing organisations that were deemed to be world class or aspiring to be world class.

Organ-isation	Manufacturing Capabilities				Performance		
	Cost	Quality	Flexibility	Delivery	Sales per Employee (£)	Economic Value Added (EVA)	Profit (%)
A	26.0	26.0	25.0	21.0	38,842.22	7.03	10.22
B	32.0	18.5	22.5	22.5	202,318.18	9.67	11.88
C	27.0	27.0	25.0	21.0	151,891.89	38.95	42.70
D	12.5	19.0	17.0	13.0	28,750.00	12.1	14.78
E	22.0	29.0	18.0	17.0	51,652.54	5.21	10.50
F	25.0	23.0	20.5	16.0	82,291.67	3.89	4.81
G	34.0	22.0	16.0	25.0	122,950.82	25.33	26.67
H	31.0	32.0	23.0	16.5	81,265.82	18.28	24.20
I	27.0	28.0	10.0	15.0	53,179.19	8.95	13.04
J	26.0	34.0	23.0	21.0	67,301.79	5.74	10.94
K	27.0	35.0	23.0	19.0	86,581.80	11.74	13.21
L	28.5	24.5	15.5	20.5	486,666.67	3.74	4.79
M	31.0	26.0	16.0	19.0	90,643.27	2.74	4.52
Mean	26.85	26.46	19.58	18.96	118,795.07	11.80	14.79
Standard Deviation	5.39	5.20	4.53	3.34	120,400.43	10.36	10.73
Maximum	34.00	35.00	25.00	25.00	486,666.67	38.95	42.70
Minimum	12.50	18.50	10.00	13.00	28,750.00	2.74	4.52

Table 7.1 Scoring for Manufacturing Capabilities and Organisations Performance

The performance measure for each organisation was determined by benchmarking it against the best performance in the Mx2000 study. This enables a primary fitness value to be calculated. From this value an average fitness value is calculated based on the average of all three primary fitness values (Sales per employee, Economic Value Added, Profit). In other words, all three primary fitness values carry the same weighting. To determine the relative fitness, a benchmark for each organisation against the best fitness of the 13 organisations was taken. Table 7.2 shows the primary fitness, mean fitness and relative fitness values for the organisations.

Organisation	Primary Fitness			Fitness	
	Sales per Employee (£)	Economic Value Added (EVA)	Profit (%)	Means Fitness	Relative Fitness
A	0.08	0.18	0.24	0.17	0.22
B	0.42	0.25	0.28	0.32	0.41
C	0.31	1.00	1.00	0.77	1.00
D	0.06	0.31	0.35	0.24	0.31
E	0.11	0.13	0.25	0.16	0.21
F	0.17	0.10	0.11	0.13	0.16
G	0.25	0.65	0.62	0.51	0.66
H	0.17	0.47	0.57	0.40	0.52
I	0.11	0.23	0.31	0.22	0.28
J	0.14	0.15	0.26	0.18	0.24
K	0.18	0.30	0.31	0.26	0.34
L	1.00	0.10	0.11	0.40	0.52
M	0.19	0.07	0.11	0.12	0.16
Mean	0.25	0.30	0.35	0.30	0.39
Standard Deviation	0.25	0.27	0.25	0.18	0.24
Maximum	1.00	1.00	1.00	0.77	1.00
Minimum	0.06	0.07	0.11	0.12	0.16

Table 7.2 Manufacturing Fitness

7.3.1 Regression Analysis between Capability and Fitness

As it is the speculation of this study that there are some forms of relations among four manufacturing capabilities and organisations' relative fitnesses, regression analysis will be used in the first stage of investigation. The general objective of a *regression analysis* is to use information about x to draw some type of conclusion concerning y when these two variables x and y are given.

Table 7.3 contains the scoring for each manufacturing capability and an additional column - the aggregate scoring of the four capabilities.

Organisation	Manufacturing Capabilities					Relative Fitness
	Cost	Quality	Flexibility	Delivery	Aggregate scoring	
A	26.0	26.0	25.0	21.0	98	0.22
B	32.0	18.5	22.5	22.5	95.5	0.41
C	27.0	27.0	25.0	21.0	100	1.00
D	12.5	19.0	17.0	13.0	61.5	0.31
E	22.0	29.0	18.0	17.0	86	0.21
F	25.0	23.0	20.5	16.0	84.5	0.16
G	34.0	22.0	16.0	25.0	97	0.66
H	31.0	32.0	23.0	16.5	102.5	0.52
I	27.0	28.0	10.0	15.0	80	0.28
J	26.0	34.0	23.0	21.0	104	0.24
K	27.0	35.0	23.0	19.0	104	0.34
L	28.5	24.5	15.5	20.5	89	0.52
M	31.0	26.0	16.0	19.0	92	0.16
Mean	26.85	26.46	19.58	18.96	91.85	0.39
Standard Deviation	5.39	5.20	4.53	3.34	11.94	0.24
Maximum	34.00	35.00	25.00	25.00	104	1.00
Minimum	12.50	18.50	10.00	13.00	61.5	0.16

Table 7.3 Scoring for Manufacturing Capabilities and Relative Fitness

To test the relationship between capabilities and fitness, regression analysis calculated by the least-squares line through SPSS will be used as in the following two sub-sections.

7.3.1.1 Regression Analysis between Aggregate Capability and Fitness

The general linear regression model relating a dependent variable y to an independent variables x is specified by the model equation

$$y = a + bx$$

where the value of b, is called the slope of the line, and a is the intercept of the line.

In this analysis, the dependent variable is fitness, where the independent variable is the aggregate scoring. Table 7.4 shows the linear regression analysis that has been generated by the SPSS software.

Linear Regression analysis

Dependent variable	Fitness
Multiple *R*	0.303
R-square	0.092
Adjusted *R*-square	0.009
Standard error	0.239

Analysis of variance

	df	*Sum of squares*	*Means square*
Regression	1	0.063	0.063
Residual	11	0.626	0.057
Total	12	0.690	

F = 1.113   Significance *F* = 0.314

Variable	Coefficients	Standard Error	T value	P-value
Aggregate	0.0061	0.0058	1.0552	0.3140

Table 7.4 Linear Regression Analysis

Shown in Table 7.4, the coefficient of determination, R^2 is 0.092 and is close to zero. This suggests that there is no linear relationship between the aggregate capabilities and fitness. On the other hand, in the analysis of variance the value of F is 1.113 with a significant value of 0.314. This indicates that the hypothesis that $R^2 = 0$ is not rejected. Therefore, these evidences suggest that although there is no linear relationship, there may be some associations between the two variables.

7.3.1.2 Multiple Regression Analysis between four Capabilities and Fitness

The general additive multiple regression model relating a dependent variable y to k independent variables $x_1, x_2, \ldots, x_k$ is specified by the model equation

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + e$$

The random deviation e is assumed to be normally distributed with mean value 0 and standard deviation σ, whenever the values of $x_1, x_2, \ldots, x_k$. The individual β_i's are called population regression coefficients.

In this analysis, the dependent variable is fitness, where the independent variables are cost, quality, flexibility and delivery. Table 7.5 shows the multiple regression analysis.

Multiple Regression analysis

Dependent variable	Fitness
Multiple *R*	0.45
R-square	0.20
Adjusted *R*-square	-0.20
Standard error	0.26

Analysis of variance

	df	*Sum of squares*	*Means square*
Regression	4	0.14	0.03
Residual	8	0.55	0.07
Total	12	0.69	
F = 0.50	Significance *F* = 0.74		

Variable	Coefficients	Standard Error	T value	P-value
Cost	0.0034	0.021	0.160	0.877
Quality	-0.0049	0.016	-0.303	0.770
Flexibility	0.0075	0.019	0.384	0.711
Delivery	0.0233	0.036	0.640	0.540

Table 7.5 Multiple Regression Analysis

As shown in Table 7.5, the coefficient of determination, R^2 is 0.2. This indicates that there is a linear relationship between the four capabilities and fitness. However, this value indicates that there is other dependent variables that are absent in this analysis. Furthermore, from the analysis of variance, the value of F is 0.50 with a significant value of 0.74. This indicates that the hypothesis that $R^2 = 0$ is not rejected.

The importance of the four capabilities (in descending order) are delivery, flexibility, cost, and quality. However, the P-values for these four capabilities are 0.540, 0.711, 0.877, 0.770 respectively. These figures show that none of the manufacturing capabilities were significantly related to manufacturing fitness at 5% confident level.

Hence these results from the multiple regression analysis indicate that there are some connections between the four manufacturing capabilities and manufacturing fitness. Therefore, there is a need for further analysis to find the associations between these variables.

7.3.2 Converting the Manufacturing Capability

From the last section, there is no statistic support using regression analysis between the individual manufacturing capabilities and relative fitness. Hence this study proceeds to find the relationship of the manufacturing capabilities using method suggested in Section 7.2.3.

In Table 7.1, it contains the mean score for each manufacturing capability. These mean scores are used as partition values to indicate whether an organisation has deployed the understudied capabilities or not. For those capabilities that score above the mean, a value of 1 is allocated, whilst a score below the mean results in a value of 0 (see Table 7.6).

Organisation	Manufacturing Capabilities*				Relative Fitness
	Cost	Quality	Flexibility	Delivery	
A	0	0	1	1	0.22
B	1	0	1	1	0.41
C	1	1	1	1	1.00
D	0	0	0	0	0.31
E	0	1	0	0	0.21
F	0	0	1	0	0.16
G	1	0	0	1	0.66
H	1	1	1	0	0.52
I	1	1	0	0	0.28
J	0	1	1	1	0.24
K	1	1	1	1	0.34
L	1	0	0	1	0.52
M	1	0	0	1	0.16

* The value 0 represents that the capability is non-existence, whilst value 1 represents that capability is existence.

Table 7.6 Modified Manufacturing Capabilities

The figures in Table 7.6 will be used for the calculations in the following sub-sections.

7.3.2.1 Comparison of Single Manufacturing Capability

By consolidating and averaging out the fitness traits of each manufacturing capability for the organisations Table 7.7 is produced. This shows the different fitness values for the existence or non-existence of each manufacturing capability.

Manufacturing Capability	Non-existence (Value = 0)	Existence (Value = 1)	Changes in fitness	Changes (%)
Cost	0.23	0.49	0.26	113.04
Delivery	0.30	0.44	0.14	46.67
Quality	0.35	0.43	0.08	22.86
Flexibility	0.36	0.41	0.05	13.89

Table 7.7 Fitness Table Comparing Single Manufacturing Capability

Table 7.7 reveals several observations along with metrics by which to gauge the impact of each observation. For instance, if we consider the cost capability, we see that the fitness values for the existence or non-existence of cost is 0.49 and 0.23 respectively. This represents a 113.04% difference in fitness, which is the greatest change in percentage for all the capabilities. This confirms that regardless of the latest initiative or management trend the value and importance of cost is paramount. It is a defining capability. Surprisingly the improvement of having the quality capability is relatively small (22%) and a possible for reason for this is that quality has now become standard for most manufacturers and a plateau has been reached.

7.3.2.2 Comparison of Two Manufacturing Capabilities

This section compares the fitness of organisations that engage activity/inactivity in the dual-capability combination. For example, for the combination cost-flexibility, there are two organisations, Organisation ***D*** and Organisation ***E*** with fitness values of 0.31 and 0.21 respectively, that are found without this dual-capability. Therefore the average fitness for organisations that lack of these two capabilities is 0.26. On the other hand, there are four organisations, Organisation ***B***, Organisation ***C***, Organisation ***H*** and Organisation ***K*** with fitness of 0.41, 1.0, 0.52 and 0.34

respectively that have this dual-capability. Hence, the average fitness of organisations that have these two capabilities is 0.57. Table 7.8 illustrates the impact on fitness when two manufacturing capabilities are combined for all the dual-capability combinations.

Manufacturing Capability	Non-existence (Value = 0)	Existence (Value = 1)	Changes in fitness	Changes (%)
Cost-Flexibility	0.26	0.57	0.31	119.23
Cost-Quality	0.23	0.54	0.31	134.78
Quality-Flexibility	0.41	0.53	0.12	29.27
Quality-Delivery	0.24	0.53	0.29	120.83
Cost-Delivery	0.23	0.52	0.29	126.09
Flexibility-Delivery	0.27	0.44	0.17	62.96

Table 7.8 Fitness Table for Combination of Two Manufacturing Capabilities

Observations from Table 7.8 include:

1) Generally, the cost capability combined with the other manufacturing capabilities tends to outperform the other combinations. This agrees with the arguments presented in Chapter 6 that cost is a fundamental and underpinning capability.
2) Comparing Table 7.7 and Table 7.8, all the fitness values for two manufacturing capabilities outperform any single manufacturing capability. This is evidence that it is beneficial for manufacturing organisations to deploy more than one capability.
3) Generally, the combinations of the quality capability are consistent with a value of around 0.53. The only small exception is when quality is combined with cost to produce a fitness value of 0.54
4) The delivery capability combinations are observed to be the lowest, with the flexibility/delivery combination having a value of 0.44.

Table 7.9 provides a matrix to illustrate the various manufacturing capability combinations.

Manufacturing Capability	Cost	Flexibility	Delivery	Quality
Cost	0.49			
Flexibility	0.57	0.41		
Delivery	0.52	0.44	0.44	
Quality	0.54	0.53	0.53	0.43

Table 7.9 Fitness Table Comparing between One and Two Manufacturing Capabilities

7.3.2.3 Comparison of Three and Four Manufacturing Capabilities

Table 7.10 illustrates the impact on fitness when three and four manufacturing capabilities are combined.

Manufacturing Capability*	Non-existence (Value = 0)	Existence (Value = 1)	Changes in fitness	Changes (%)
CQD	0.24	0.67	0.43	179.17
CQF	0.31	0.62	0.31	100.00
CFD	0.26	0.58	0.32	123.08
QFD	0.31	0.53	0.22	70.97
CQFD	0.31	0.67	0.36	116.13

*Note: C = Cost, Q = Quality, F = Flexibility, D = Delivery

Table 7.10 Fitness Table for Combination of Three Manufacturing Capabilities

Observations from Table 7.10 include:

1) The combination of cost/quality/delivery has the highest fitness value of 0.67. This again suggests that a combination of multiple capabilities creates a relatively good fitness.
2) Generally, the fitness performances in Table 7.10 are no worse compared to the performances shown in Table 7.9. In other words, organisations with three capabilities generally perform better than those with two capabilities. This contradicts the trade-off theory discussed in Chapter 6.

3) There are two combinations of manufacturing capabilities (cost/quality/delivery and cost/quality/flexibility/delivery) that achieved the highest fitness value of 0.67.
4) For quality/flexibility/delivery the fitness value is 0.53. This means that no fitness is gained for organisations that possess quality/flexibility and quality/delivery both of which have the same fitness value of 0.53.

7.3.3 Mapping of Manufacturing Capabilities

The tables presented above provide interesting insights into the combination of capabilities, but they contain limited information about why certain combinations have certain fitness values. It is difficult to compare the different combinations especially the bi-capability and tri-capability combinations. Also, it is difficult to understand how such capabilities should be implemented. However, these difficulties can be overcome by plotting the information in a manner which is consistent with fitness landscape theory. The method adopted is that which was disused in Chapter 4 - a Boolean hypercube. Figure 7.1 shows a Boolean hypercube for the manufacturing capabilities and their corresponding fitness values shown in Table 7.7 - 7.10.

Figure 7.1 uses a binary notation to represent the status of manufacturing capabilities in the following order, cost, quality, flexibility and delivery. A value of 1 indicates the existence of a capability, whilst the value 0 indicates the non-existence of a certain manufacturing capability. For example, 0011 indicates that flexibility and delivery are present and that cost and quality are absent. Also, 1011 denotes the existence of all capabilities except quality. The nought capability, i.e. 0000 is at the top of the diagram, whilst the full capability, i.e. 1111 is situated at the bottom of the diagram. As an organisation aggregates additional capabilities, it descends into the lower parts of the diagram. The fitness value for the various combinations of capabilities is represented by the bracketed figure. Lines are used to connect two immediate neighbours and the direction of the arrowhead indicates an increase in fitness or "climbing" (see discussion in Section 4.2). The dotted line indicates that the two neighbours are of the same fitness and therefore, no climbing is present.

When all the arrowheads are directed to a single point, this point is said to be an optimal (either local or global). These optimal points are distinguished from the others by the use of dotted line circles. In Figure 7.1, there are two optimal points 1101 and 1111 with fitness values of 0.67. It is also important to note that these optimal points involve three capabilities: cost, quality and delivery.

Figure 7.1 shows all arrows as pointing downwards. This is considered to be a condition of the cumulative nature of these manufacturing capabilities. However, there are some exceptions. There is no increase in manufacturing fitness for organisations that implement flexibility in addition to the capability of delivery. The value for manufacturing fitness remains at 0.44. In another instance, the quality capability combined with delivery or flexibility has the same fitness value of 0.53, even if the three capabilities are deployed consecutively. This unity phenomenon between delivery and flexibility capability should be investigated further.

Identifying the steepest ascending path is a logical approach for getting to the highest point. This path is represented by the bold lines in Figure 7.1. This informs an organisation of the order of implementation (1^{st} cost, 2^{nd} flexibility, 3^{rd} quality and 4^{th} delivery) to reach the optimal point of 0.67. On the other hand, the same fitness can be achieved by implementing cost, quality and delivery.

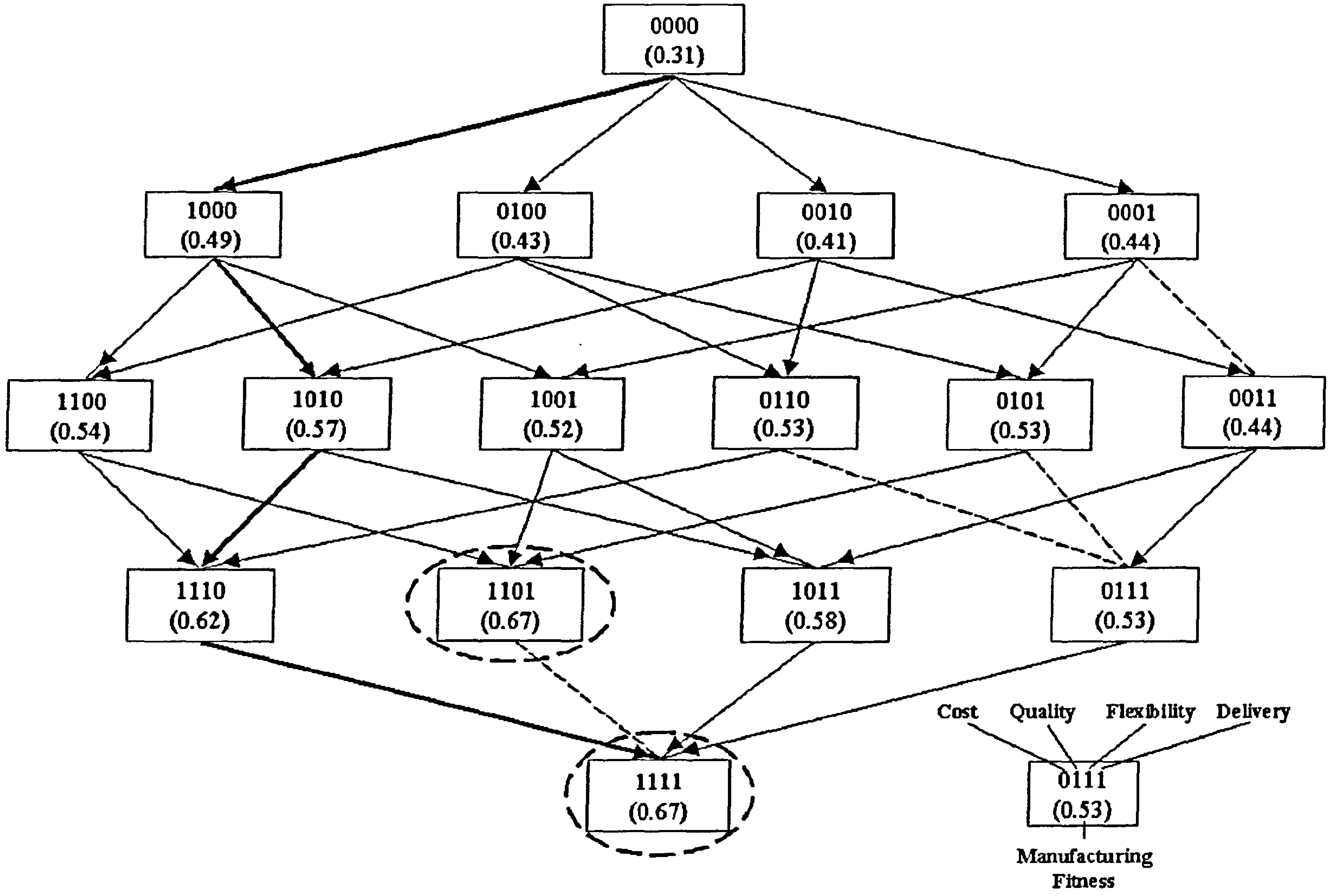


Figure 7.1 Boolean hypercube for Manufacturing Capabilities

7.3.4 Discussion on Capabilities Mapping

For a single capability, the cost capability has the highest fitness value. One of the reasons for this is the importance and role of financially based performance measurements (Profit, Economic Value Added and Sale per employee) used in the Mx2000 study. Nevertheless, the findings of this fitness mapping are consistent with the studies carried out by Yeung and Chan (1998). Using the case studies of six firms, Yeung and Chan found that these firms had increased their market share by providing their customers with products at low prices. This was achieved despite the firms' pledge to implement quality and flexibility capabilities at the expense of cost. Therefore, although it is an obvious statement, most organisations do not exist in a "cost plus" environment regardless of how good their quality, flexibility and delivery is. Beach et al. (2000) also provided evidence that the cost capability is still perceived as the most important order-winner for UK manufacturers, and Roth and Miller (1992) noted that quality is necessary, but is not a sufficient factor for competition.

For two capability combinations, it was surprising to find that the cost/flexibility combination had a higher fitness value that the cost/quality combination. This contradicted the observations made in Section 6.4 using the model presented by Figure 6.3 . However, this observation was consistent with findings made by Mapes et al. (1997) that the cost and quality capabilities were not significantly related. Also, in a recent study, Ward and Duray (2000) found a positive correlation between cost and flexibility, with flexibility being an important enabling factor for customisation. This is an emerging source of competitive advantage after the quality capability (Hayes and Pisano, 1994). Newman et al. (1993) also suggested that the flexibility capability could reduce the uncertainty faced by manufacturers, by helping then to respond or reconfigure their operations. These uncertainties include internal uncertainties (machine failures, lack of materials, delays, etc.) and external uncertainties (demand variations, supply variations, unfavourable legislation, etc.).

Therefore, flexibility acts as an absorber of uncertainty. In 1995, Upton (1995) recognised the term "flexibility" was only at a primary stage of exploitation and needed to be explored in a similar way to which the quality capability had been two decades previously. Although, the meaning of manufacturing flexibility is still imprecise, it is critical to competitiveness. This is demonstrated by the Mx2000 study and the role of flexibility in the map presented in Figure 7.1.

Figure 7.1 illustrates that there are two optimal points. These points are clustered around three capabilities: cost, quality and delivery. This finding concurs with the proposition suggested by Corbett and Vanwassenhove (1993) that an organisation's competitiveness should be built on these three capabilities. In another study focusing on manufacturers in Singapore, Ward et al. (1995) found that these three capabilities could be found in high performers whom were facing high levels of unpredictable in a turbulent manufacturing environment.

The above commentary demonstrates the value of using a graphical and fitness based concept to explore the credibility and validity of different capability configurations. The manufacturing capability map (Figure 7.1), the fitness pyramid (Figure 6.3) presented in Section 6.4 can now be summarised using Figure 7.2. The cost capability forms the foundation of the pyramid. Any additional capability built upon this foundation increases manufacturing fitness. The quality and flexibility capabilities are built on top of the cost capability, as they form a stable structure for future improvement. Then the delivery capability is mounted on these two capabilities.

The reason why the second layer of the pyramid is split between two capabilities - quality and flexibility is to discourage the path of achieving high fitness by passing through the cost/flexibility/delivery combination which has a relatively low fitness value. It is important to note that the second layer is not evenly split among these two capabilities - quality and flexibility. This inequality is deliberate for two purposes. Firstly, this is to deter the implementation of cost/flexibility/delivery combination. Secondly, it is feasible for the implementation of the cost/quality/delivery combination as this combination has a higher fitness value.

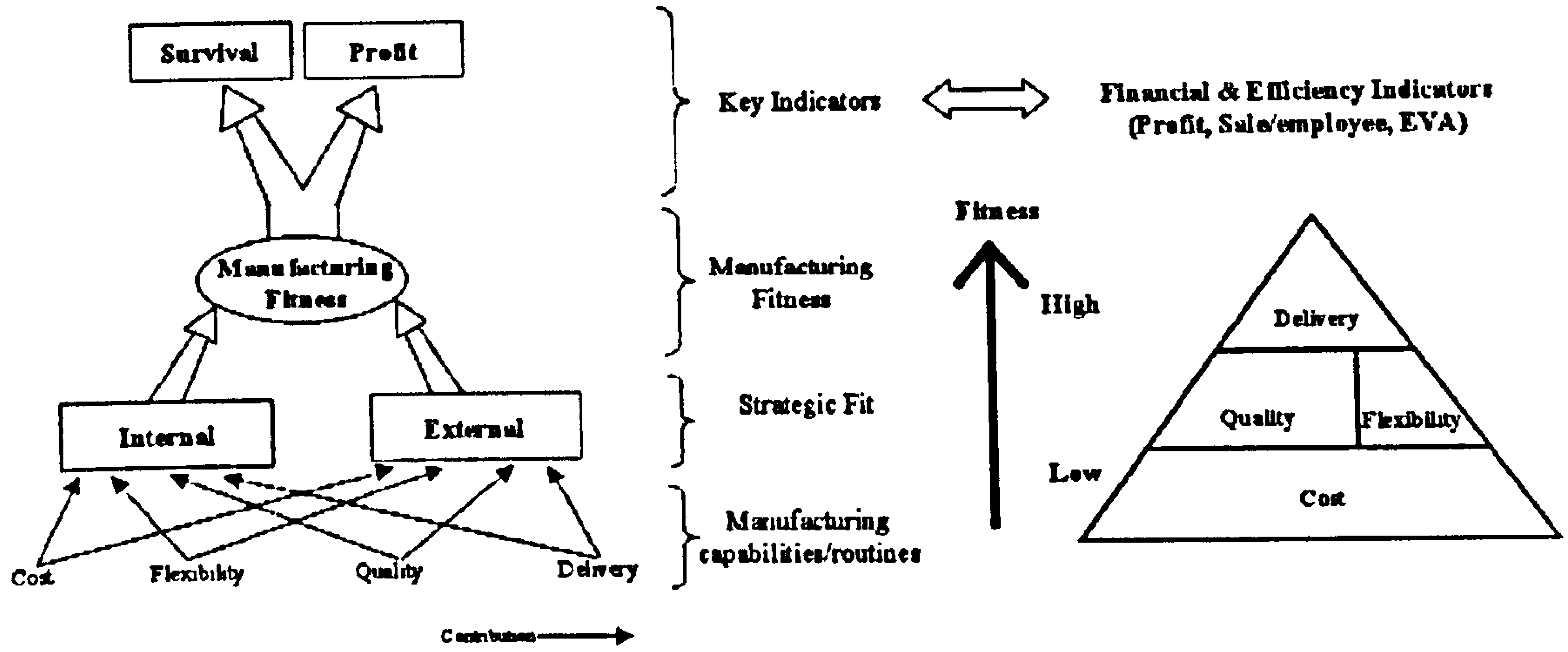


Figure 7.2 Modified Fitness Pyramid

7.4 Conclusion

Using the data from the Mx2000 competition, this chapter presented, applied and tested the calculations for determining manufacturing fitness for a population of manufacturing organisations. It also detailed the formulae for uniting several performance measurements into one unit of fitness measurement in order to make comparisons between organisations. By associating manufacturing fitness with the manufacturing capabilities used, the fitness values for different combinations of manufacturing capabilities were determined. A mapping of these different combinations was presented and discussed. This map or landscape was then presented as a navigating tool to help inform and guide manufacturing organisations when they explore new manufacturing capabilities.

By using a fitness landscape approach to evaluate manufacturing strategy, capabilities and performance on the Mx2000 competition data, the following observations were made:

- Cost capability was found to be the highest and most beneficial among the individual core capabilities.
- Cost capability combined with the flexibility capability is the most worthwhile union among the bi-capabilities combinations.

- Using steepest ascending method, the sequence of capabilities to be implemented is cost, flexibility, quality and lastly delivery.
- The highest fitness value could be achieved by either deploying cost-quality-delivery capability or all four capabilities.
- The manufacturing fitness map provides evidence that manufacturing capabilities are of a cumulative rather than trade-off nature.

Chapter 8. Conclusion

8.1 Introduction

Throughout this thesis, each chapter presented a conclusion that contributes or advances this research towards its objectives. This chapter presents an overview of the realisation of the objectives listed in Chapter 1, whilst summarises the contribution made to knowledge.

The chapter begins by reviewing the research methodology that marshals this research. It is important to discuss the method so that the strengths and limitations of this thesis are in context and that lessons may be gauged. The second section of this chapter reviews the fulfilment of the aims and objectives that initiated and drove this research. This section also presents the novelty created by this research. Finally, the chapter concludes by outlining several recommendations and proposals for further advancing the study of manufacturing strategy and capabilities using fitness landscape theory.

8.2 Research Methodology

At the research design stage, it was initially believed that the research phases could be easily distinguished from one another. Hence Figure 1.1 presented in Chapter 1 showed the logical and analytical thought processes as a linear flow between the various stages. However, as the research developed, it was clear that the various stages are not linear in flow, but are intricately entangled together with several feedback loops and iterations. Furthermore, the knowledge and findings created at each research stage impacted and developed the researcher's understanding of the earlier stages. This introduced the feedback and iterations and meant that on several occasions certain sections of the thesis were revisited before advancing the research.

Nevertheless, this research can be divided into five different stages: *needs analysis, review of relevant concepts, formulate fitness model, application of model* and *review and conclusion.* These five stages are naturally differentiated, but they also have significant areas of overlap. To indicate thus the various stages of the research are presented in Figure 8.1.

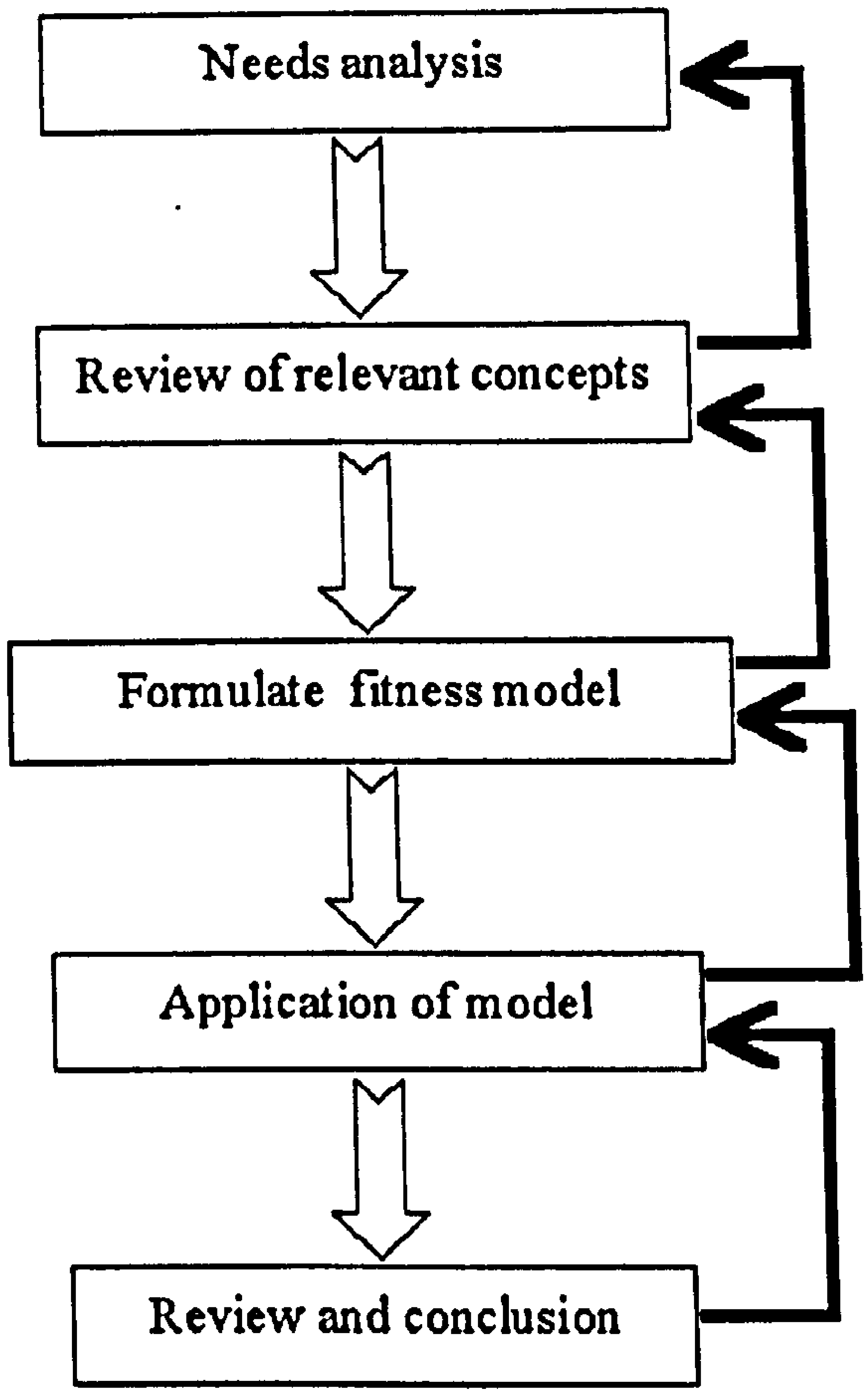


Figure 8.1 Modified Research Process

In summary, it is useful for researchers to have a research program or structured plan that will help guide and facilitate the research process, but it is important to note that this plan is simple a template and that as the research process unfolds it will often follow a similar, but more complicated path. Therefore, the purpose of this research process is two fold, firstly to achieve the research aims and secondly to assist the researcher in conducting high-quality research.

8.2.1 Discussion on Secondary Data Method

Studies that use survey design data can utilise either primary or secondary data. This study used the Mx2000 data which was an up to date and targeted secondary data source. The main advantage of using this secondary data was the huge saving in resources, in particular time and expenditure. The Mx2000 data was provided to this study in order to assist the study of manufacturing excellence. Although several subsidiary activities were required, for example telephone conversations and meetings with the Mx2000 organisers, the overall cost of using this data was minimal. By using the Mx2000 data more time could be allocated to understanding and developing the theory that underpins the research concepts and in analysing the data. Also, the disclosure and availability of business and manufacturing data, especially financial data, often makes documentation and publication difficult, but with the Mx2000 data, the participating organisations had agreed to submit sensitive information that could be used for competition purposes and for studying manufacturing excellence.

Using secondary data is not without drawbacks. One of the biggest faced by this research was the relatively small sample size. Since the Mx2000 competition was a prestigious event for UK manufacturing organisations, "average" performing organisations were reluctant to participate. This obviously reduced the number of the participants, but it did attract organisations that were likely to be world class or leaders in their field. This helped focus the reliability of the data gathered through the questionnaires. Another drawback faced by this research is the common debate that accompanies the use of performance measurements. For the Mx2000 competition, the focus was solely on manufacturing excellence led by financial performance, but supported by relevant manufacturing capabilities and operational characteristics.

8.3 Research Aims and Objectives

The purpose of this research was to study the development and application of fitness landscape theory (a theory that is part of complex systems theory) in order to assist the formulation of manufacturing strategies. Therefore, the research effort and novelty within this thesis focused on:

- What is complex systems theory and what is its relevance to manufacturing?
- From a complex systems perspective, what is fitness in a manufacturing context?
- What are the implementations and applications of fitness landscape theory?
- How can the concept of manufacturing fitness be modelled and applied?

The following sections summarise the answers and novelty produced by this thesis.

8.3.1 Complex Systems Theory

The first objective of this research was to examine the emerging theory of complex systems. Advocates of this theory observe that most real-world systems are complex systems in that they possess simple components that interact non-linearly with other components and these collective behaviour will form the basic characteristics or building blocks of a higher system level. Such systems and the observations made about them are contradictory to the mechanical and simple view held by orthodox researchers.

As stated above complex systems are synergistic and the systems have properties that do not correlate to the sum of the systems individual part properties. With this belief, the system is studied as a whole and not in separated components and the consequence has been several tools, ideas and metaphors. Chapter 3 explores each of these tools, ideas and metaphors and presents a framework (see Figure 3.6) for understanding how they relate to each other and issues of manufacturing strategy and operations. Chapter 3 also introduces the notion of a specific type of complex systems - a *complex adaptive system*. The main characteristics possessed by a complex adaptive system is that the system behaviour emerges from the interaction of large numbers of simple components, but it is also able to adapt. In other words it is able to improve its performance over time in response to what has been encountered previously. Some complex adaptive systems demonstrate goal directed adaptation i.e. they are able consciously influence their adaptation according to goals or rules. This is the case for manufacturing organisations.

By treating manufacturing organisations as complex adaptive systems, this research was able to exploit complex systems knowledge and in particular fitness landscape theory.

8.3.2 Implementations and Applications of Fitness Landscape Theory

Several researchers (Maguire, 1997b; Merry, 1998; Beinhocker, 1999) had noted that fitness landscape theory was an appropriate theory for investigating and understanding strategy, but none of these papers made any attempt to:

- Fully understand fitness and relate it to organisations in terms of competitiveness, effectiveness or survival.
- Define organisational or manufacturing fitness and develop a model.
- Develop and apply fitness landscape theory to organisations.

This gap was both the motivation and novelty that underpins this research.

Fitness landscape theory was developed from a biological genesis. The evolution of organisms are portrayed as a hill climbing process with fitness represented by varying heights on an evolutionary landscape. To understand this evolutionary process more clearly, Kauffman (1993) developed a NK fitness landscape model, in which the methods and terminology used are explained in Chapter 4.

The shape of the landscape is important as it suggests certain survival conditions and strategies. *Correlated landscapes* are smooth with comparatively few peaks and the size of the improvement steps is very small, i.e. the slopes are gentle. By contrast, *rugged landscapes* have lower optima with deep valleys and steep falls. NK models provide insights into the factors that contribute to the different stages of co-evolution. These include the internal-connectivity (K factor) and external-connectivity (C factor) their relation to all the factors (N factor). As internal-connectivity increases from zero to the maximum connection, the fitness landscape changes from a smooth, correlated and single peak optimum to a rugged, uncorrelated, and multi-peaked landscape. External-connectivity influences how the different species react to the action of others, because the behaviour of one species could alter the face of the landscape purposely or unintentionally. Also, this model illustrates how co-evolution can be orderly, chaotic, or at the edge of chaos or self-organising.

This focus of the thesis confirmed that fitness landscape models could be applied to wider issues such as organisational structure, firm size, or organisational strategy, etc. This in turn led to the focus that manufacturing organisations exist by selecting certain core capabilities. By concentrating on core capabilities, organisations could "optimise" their manufacturing fitness by effectively exploiting the management of resources. Also, fitness landscape models provide an effective way of "mapping" organisational strategies.

8.3.3 The Definition of Fitness

The third objective of this research was to determine the meaning of "fitness" in terms of its biological and complex systems context and to relate this meaning to manufacturing organisations. By reviewing the vast amount of literature on the definition of biological fitness it soon became apparent that finding a unified definition of fitness would not be straight forward. To understand the different points of view concerning this term a collective definition of biological fitness was presented in Chapter 5.

In biological terms, natural selection will cause changes in allele frequencies. This is because certain organisms will have a greater success in surviving and reproducing and they will pass their genes to the next generation. As a consequence of this hereditary process, these genotypes appear more frequently as the organisms that contain these particular genes also become more numerous. It is with this knowledge that the fitness of an organism can be determined. Population geneticists' consider fitness to the observable effect, i.e. the reproduction rate of the species and the history of the species.

With this definition, this thesis proceeded to create a definition for organisational fitness. This was achieved by conducting a detailed review of the literature that deals with organisational effectiveness and organisational evolution and population ecology. When reviewing organisational effectiveness it was found that a similar situation existed, in that the research community offered a diverse range of definitions on what constitutes an effective organisation. This issue is further confused by the lack of agreement on the definition of organisations themselves. Despite the difficulties of vocabulary (which accompany most management research programmes) a robust and rigorous definition of organisational fitness was developed and proposed: *the ability for organisations to increase their survivability and long-term growth within its interacting environment, through inheriting, imitating and searching short-term routines or criteria (measurable or immeasurable) such as production, quality, efficiency, flexibility, satisfaction etc.* Routines are a generic term that can be used to describe organisations in terms of their form, rules, procedures, conventions, strategies, and technologies. These are the factors on which organisations are constructed and through which they operate.

Finally, using the organisational fitness definition, a definition of manufacturing fitness was constructed. Since manufacturing organisations exist to create wealth for their owners and stake holders, its main concern is to produce profit. Therefore, fitness in a manufacturing context means that the organisation can compete successfully and generate a profit in a local or global environment. This activity needs to be achieved now, but also importantly in the future. In order to make a profit, manufacturing organisations should be able to competitively differentiate and sell their products. Product value is perceived by the customer and includes many factors, but primarily involves a combination of quality, price, availability, after-sale service, and product performance/capability. Therefore, manufacturing fitness is *the ability for manufacturing organisations to increase their survivability and competitiveness in the manufacturing environment, through inheriting, imitating and searching manufacturing strategy (or routines) such as quality, delivery, flexibility, and cost.*

8.3.4 Development of Fitness Model

Skinner (1969) emphasised the importance of the trade-off concept in the development of manufacturing strategy. In his opinion, trade-off was necessary as manufacturing companies are not able to handle effectively all capabilities and therefore should concentrate on a select few. This concept led to the development of the *focused manufacturing strategy*. However, an opposing view emerged based on the success of Japanese managed manufacturing plants. In these plants it was observed that it was feasible to effectively operate every known manufacturing capability. With these multi-capabilities these organisations were achieving significantly superior manufacturing performance that was translating into corresponding profit and market share levels. This activity led to the *accumulative model.*

However, the debate between the trade-off model and the accumulative model is complex, because the consequences of each strategy can have unpredictable outcomes. Chapter 6 presented empirical evidence that challenges the trade-off concept, but still there is no conclusive decision on which is the best approach. With this background, this thesis sought to create an innovative method for surveying the impact that manufacturing capabilities can have on fitness. This method illustrates the outcome of a landscape model using a mapping technique that relates manufacturing performance to manufacturing capabilities. In this research, four manufacturing capabilities, cost, quality, flexibility and delivery were studied thoroughly. The various combinations of these four capabilities, sixteen to be exact, are presented in Figure 7.1. From this diagram, it can be seen that the combinations are obvious accumulations, with a few exceptions that involve the combination of delivery and flexibility capabilities. Organisations that engage in quality, delivery and flexibility capabilities have the same manufacturing fitness as those engaging in quality and delivery only, or quality and flexibility only. Likewise, organisations that engage in delivery and flexibility capabilities hold the same fitness level as those organisations engaged in single delivery capability.

From the map there are two points that have high fitness values. They are clustered around three capabilities: cost, quality and delivery. An organisation that travels along the steepest path will reach one of the two peaks, but with a longer track. This is because this method needs to employ four capabilities (cost, quality, flexibility and delivery) in order to reach the peak. The sequence for the capability of this method is cost, flexibility, quality and delivery. Organisations with any capability combinations can reach any one of the peaks in a maximum of four steps. By providing such a mapping that contain these four capabilities, manufacturing managers can use this tool as a navigating tool to guide them through the mist and uncertainty in the formulating of manufacturing strategy.

8.3.5 The Utility of this Research

Humans possess a supernatural and mysterious type of intelligence, commonly know as spatial or geographic intelligence. This spatial intelligence is the ability to orientate oneself in space and time and to understand how the landscape or terrain is organised and to use navigating tools such as compasses and maps to travel through unknown or unfamiliar territory. The aim of this study was not to re-invent manufacturing capabilities or to identify new capabilities, but to create a method that would help manufacturing strategy-makers steer and navigate their way through the decision making process of formulating strategy that will enhance their fitness.

Based on this conceptual fitness model and using the empirical data from the Mx2000 sample, this research provided a navigating tool for the manufacturing managers. This navigating tool can be used to understand the conceptual landscape of manufacturing capabilities. Within this map, it provides the relative manufacturing fitness for different combination of capabilities.

To advance the organisation to a higher point, there are three important steps to carry out. Firstly, manufacturing managers have to determine the organisation's current fitness by assessing its current strategic standing. Secondly, there must be agreement about the determination of the manufacturing capabilities required for attaining the organisation's progress. Finally, the organisation has to adopt relevant programs to realise and practice the targeted capabilities. It is through these above-mentioned activities that the manufacturing map can be beneficial to manufacturing organisations. Furthermore, with these activities, the organisation is enhancing and exercising its adaptability. Adaptability, in this context is the extent to which the organisation is prepared for future changes (Rolstadas, 1998). Hence there is a closely linked between manufacturing fitness and adaptability.

The manufacturing capabilities proposed within this thesis are well documented and should be applicable to most manufacturing situations. This will aid understanding of the research and help to promote its utility and value. To orientate organisations in a world that is interconnected and constantly changing, is a difficult task, even for an experienced team of chief executive officers, but it becomes more difficult when the complexity of the decision making environment increases and the rate of change quickens. If it is possible to identify a best-fit end state, strategy-makers would require a management tool that will help them identify the different paths available to them. This was the aim of this research and thus a map for illustrating the fitness of manufacturing capabilities was created.

8.4 Limitations of Research

It should be noted that the fitness model created by this research is essentially a static model, that relies on the periodic input of data about the relationship between capabilities and manufacturing fitness. As a result, the model lacks dynamic sophistication using real time updates of data. This is a shortfall that is common in management studies (for example, Mapes et al., 1997), but it does not significantly affect the value of the model. This is because manufacturing organisations, like any other organisation, require significant time periods to adjust into the new programs and modes of working. It is not uncommon for such changes to take place overall several years.

Although the Mx2000 participants provided financial data for the past 3 years, only the most current financial data was used in this research. The primary benefit of using 3 year data would have been the ability to smooth the profit variations, but this research wished to avoid the discrepancy of using data where the *financial* information might actually precede the strategy information.

8.4.1 Knowledge Limitation

As this research was motivated by three different academic areas *evolutionary biology*, *organisational studies* and *operations management*, the magnitude of the academic literature covered was vast. Therefore, it was necessary to establish boundaries to ensure that the research maintained its focus and time plan. While it is considered that the most important sources of information were consulted, it is impossible to ensure that no concepts are missed or neglected. Also, a significant aspect of this thesis involved digesting and understanding biological terminology and theories, in order to translate the relevant concepts to systems thinking, organisational studies and operations management.

8.4.2 Construct Validity

A *construct* is characterised as an abstract variable constructed, built or developed from ideas or images, which serve as a higher level explanatory term (Remenyi et al., 1998). The term fitness as used in thesis is a "construct" which was difficult to observe and measured directly. Thus, the difficulties in assessing manufacturing fitness in order to build a fitness model is construct validity problem. Construct validity is the establishment of correct operational measures for the concepts, ideas and relationships being studied. For this research, manufacturing capabilities are assumed to have an effect on the fitness of manufacturing organisations that possess such capabilities. Therefore, this research needed to establish the existence of manufacturing capabilities and the fitness of manufacturing organisations.

Each of these manufacturing capabilities is multi-faceted and complex, making interpretation difficult and subjective. However, Chapter 6 discussed and presented the different dimensions and interpretations and this was used to select the questions for the Mx2000 study.

Fitness indicator proposed by this thesis consists of several financial measures including profitability. It is important to note that profitability is a function of many variables including capital, technology, labour, organisational and managerial factors, and environmental and market factors. Thus, business unit performance is a result of co-ordinated efforts across functional areas of which manufacturing is the primary one in a manufacturing organisation (Jugulum and Sefik, 1998).

8.4.3 External Validity

External validity is concerned with the extent that the results of this research can be generalised or transferred other settings, people, or events. As participation in the Mx2000 competition was voluntary, there is a risk that this sample would not be sufficient to represent to that of all UK manufacturing plants. This worry is a major concern in any survey in which participation is not compulsory. Even when the initial sample is carefully selected to ensure that it is fully representative, there will be a proportion of non-respondents, leading to the risk of bias in the final sample. Besides, as stated before, the participants for the Mx2000 competition were likely to be above average performers. As a result, the interpretation must be done with caution. It may imply that these organisations would have extra resources (such as additional managerial posts, labour, manufacturing equipment) or additional policies (such as incentives to reach operational goals) to execute the manufacturing capabilities in studied. In other words, the resources that led to the performance level of this group of participants would not be fully representative of the resources levels for the total population of plants in the UK. Consequently, the implications of the manufacturing capabilities mapping would be restricted. Nevertheless, the fitness conception presented in this thesis examines the relativity of organisations both in the performances and capability-implementations. Hence, the fitness formulae should be applicable and extendable to other organisational types and industry sectors.

8.5 Recommendations For Future Study

This research sets the platform for further applications of fitness landscape theory to organisational and management issues, that will also develop the formation and use of NK models. Apart from repeating this research using a greater sample size and mode detailed information on capabilities (i.e. the obvious incremental developments of this work), it is proposed that the following areas for work should be address for future research activity.

- utilising the concept of fitness landscape in organisational studies, such as labour size, departments, managerial control etc.
- relating the organisational fitness in retailing or servicing environment.
- relating the concept of fitness to classic performance measurement research.
- comparing manufacturing capabilities mapping in different industrial groupings (for example, automobile, steel and hand tool industries), and analysing the industry dynamics.

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Appendix A - Manufacturing Excellence Awards (Mx2000)

The Manufacturing Excellence Awards are a long-standing initiative of the Institution of Mechanical Engineers (IMechE) to promote the important contribution made by UK manufacturing industries. This premier award scheme has gained extensive recognition over the past 21 years. Originally it was named the *Manufacturing Effectiveness Awards* and was supported by Willis Faber. Past winners of the scheme include Dunlop Sports (1982) for the development of the world's first carbon fibre reinforced thermoplastics tennis racket and the associated low melting point alloy casting process required to manufacture the frame. IBM (1986) for the manufacturing processes they developed for the production of the 9335 disc file, and British Steel's Teeside Complex (1988) for achieving the continuous use of cast slabs as feedstock for heavy beams and columns, instead of the traditional ingots. After 1994 the competition was renamed the *Manufacturing Excellence Awards* and winners included Westland Helicopters in Milton Keynes and STC Telecommunications (joint winners in 1984), GEC Alsthom Large Machines in Rugby (1992), Strix in the Isle of Man (1994), and finally Rolls Royce and M4 Data (joint winners in 1996).

Mx2000 was the latest name and evolution of scheme. It included an in-depth self-assessment audit and structured scoring system for short-listing prospective category winners. The event was elevated from the auspices of the Manufacturing Industries Division and adopted as Institution's premier award scheme. The IMechE nominated the President-elect to champion the event and to assemble a prestigious consortium of sponsors to manage and organise the event. Partners in the Mx2000 consortium included the KPMG, the Department of Trade and Industry, and the Warwick Manufacturing Group at the University of Warwick.

The aims of the award scheme are to:

- Encourage, recognise and reward best practice in UK manufacturing.
- Provide an industry benchmark for measuring success and innovation within UK manufacturing.

- Provide a benchmark of UK manufacturing at a global level.
- Identify areas of best practice for the DTI Foresight programme.
- Create a self-assessment audit that would stimulate ideas, leading to increased shareholder value.

Mx2000 promotion

The organisers promoted the awards using coverage in the national and trade press, and particularly through the IMechE's monthly magazine *Professional Engineer* which covered the event. Other means of promotion included the support from the DTI's Secretary of State for Trade and Industry, Stephen Byers, the publication of the Mx2000 magazine, and the distribution of promotional leaflets. The Department of Trade and Industry, KPMG and Warwick Manufacturing Group also promoted the event through inviting their extensive client base to enter the competition.

Appendix B - Questions Used for Manufacturing Capabilities

Quality

- Work with suppliers to develop product technology?
- Work with suppliers to improve quality systems?
- Have key internal performance measures for controlling production?
- Install the latest technology for new manufacturing processes?
- Automate inspection and test routines?
- Work with suppliers to transfer process knowledge?
- Use automated materials handling equipment?

Cost

- Have over 80% of the facilities needed to complete the manufacturing operations within a cell?
- Have continuous processes from raw material to final product?
- Regard make vs. buy as a strategic decision?
- Obtain deliveries directly to production without any inspection?
- Identify bottleneck processes as the restriction on overall capacity?
- Establish a strategic sourcing team independent of procurement?
- Give bottlenecks priority: work, people, maintenance etc?

Flexibility

- Actively develop machine changeover techniques?
- Provide changeover tools to minimise disruption to production?
- Identify and perform tasks to assist rapid production changeover prior to equipment being stopped?
- Use rapid prototyping technology to develop new products?
- Design systems with enhanced functionality providing agility to manufacture new or additional products without significant modifications to the process?

Delivery

- Introduce projects to reduce internal and external lead-times?
- Calculate the manufacturing capacity available to production in order to confirm the on-time delivery of customer schedules?
- Work on a just in time basis:- with your customers?
- Make scheduled quantities required by the customer, switching production between products as a normal way of operating?
- Operate formal rescheduling procedures?