THE UNIVERSITY OF WARWICK

Submission 10

Executive Summary

Complexity in Organisations: A Conceptual Model

by

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Abstract

Industrial organisations face uncertainty created by consumers, suppliers, competitors and other environmental factors. To deal with this uncertainty, managers have to coordinate the resources of the organisation to produce a variety of behaviours that can cope with environmental change. An organisation that does not have sufficient internal complexity to adapt to the environment cannot survive, while, an organisation with excessive complexity would waste resources and might lose its ability to react to the environment.

The main objective of the research was to create a model for dealing with complexity and uncertainty in organisations. The initial ideas for the model originated from the literature, particularly in the fields of systems and complexity theory. These initial ideas were developed through a series of five case studies with four companies, namely British Airways, British Midlands International (BMI), HS Marston and the Ford Motor Company. Each case study contributed to the development of the model, as well as providing immediate benefits for the organisations involved. The first three case studies were used in the development of the model, by analysing the way managers made decisions in situations of complexity and uncertainty. For the final two case studies, the model was already developed and it was possible to apply it, using these cases as a means of validation. A summary of the case studies is presented here, highlighting their contributions to the creation and testing of the model.

The main innovation of the research was the creation and application of the *Complexity-Uncertainty model*, a descriptive framework that classifies generic strategies for dealing with complexity and uncertainty in organisations. The model considers five generic strategies: automation, simplification, planning, control and self-organisation, and indicates when each of these strategies can be more effective according to the complexity and uncertainty of the situation. This model can be used as a learning tool to help managers in industry to conceptualise the nature of complexity in their organisation, in relation to the uncertainty in the environment. The model shows managers the range of strategic options that are available under a particular situation, and highlights the benefits and limitations of each of these strategic options. This is intended to help managers make better decisions based on a more holistic understanding of the organisation, its environment and the strategies available.

Declaration

I, Carlos Mena hereby declare that the work presented here is my own unless otherwise stated, and that none of the content has been submitted for any other award.

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1 Introduction

This document is the last one of ten submissions that comprise the project "Complexity in Organisations". The objectives of this document are to present an analysis of the evolution of the research, to demonstrate the innovations achieved and benefits obtained by the collaborating organisations, and to summarise the activities and conclusions of the research.

1.1 Background to the Research

The subject of complexity and particularly complexity in organisations has been widely debated and various authors have presented radically different views. Some authors support the idea that complexity is harmful to organisations and should be avoided (Jensen, 2000; Rommel, 1995; Shomberger, 1982, 1986), others assert that complexity is inherent in organisations but that it can be planned for and controlled (Frizelle & Woodcock, 1995; Beer, 1984). Finally, some views – supported by the development of Complexity Theory – defend the position that complexity is an essential element for the evolution and sustainability of organisations, and that it cannot be controlled, but only managed within certain boundaries (McCarthy, Frizelle, & Rakotobe-Joel, 2000, Stacey, Griffin & Saw, 2000; Maira & Thomas, 1998; Kauffman, 1995a, 1995b).

Approaches related to simplifying and controlling complexity were documented by Adam Smith as early as 1776, and appear to be the most common in industry today. On the other hand, studies related to Complexity Theory in organisations are relatively recent and there are few cases documented in the literature. This is arguably one of the reasons that the view of complexity as something negative is more prevalent in industry.

Most studies of complexity focus on either the traditional view of complexity or the Complexity Theory view and there is limited evidence to indicate that these two approaches can be combined in their application in industry. This research explores how managers are making decisions about complexity and how they are using the different views.

Complexity has benefits and limitations for an organisation. In this research these benefits and limitations are analysed and discussed and then used to create a framework of alternatives that managers can use in different situations. This framework can serve as a learning tool to help managers conceptualise the nature of complexity and the range of options that are available.

1.2 Research problem and research questions

This research explores how managers approach complex and uncertain situations and how they could benefit from Complexity Theory. It is therefore possible to formulate the following two research questions:

How do managers deal with situations of complexity and uncertainty?

How can organisations benefit from incorporating the concepts of Complexity Theory into their thinking?

In industry, managers try to understand their organisation and its environment in order to make decisions that will improve its competitive position. With this purpose in mind, they look for models that can help them make sense of the complexity and uncertainty of the situations they encounter. To answer the research questions, five case studies were conducted, looking at the strategies and approaches used in dealing with complexity and uncertainty. The main objective of the research can therefore be summarised as follows.

To create a model for dealing with complexity in organisations by exploring the use of the concepts of Complexity Theory and the approaches used by people in organisations to deal with situations where complexity is a dominant feature.

This general objective has been broken down intro three specific objectives:

1. To identify in the literature the concepts and applications of Complexity Theory that are relevant to organisations
2. To analyse the strategies used by the four selected companies to manage complexity, and to assess how the concepts of Complexity Theory can be incorporated
3. To create a model of generic strategies, which can help decision makers to understand and deal with complexity in their organisations.

1.3 Delimitations of scope

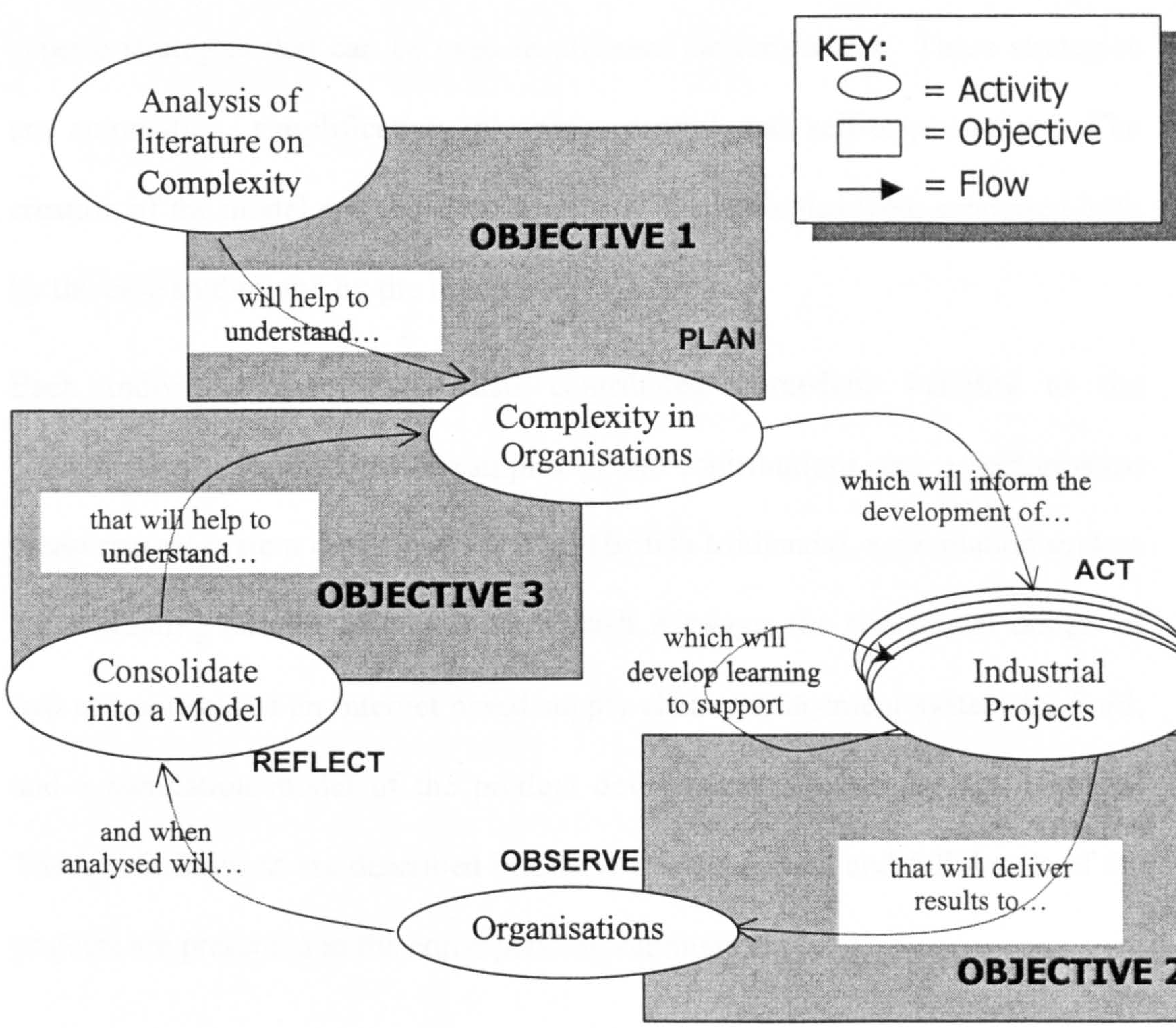
The scope of the research initially focused on engineering and logistic areas within companies in the aerospace and aviation industry. This was extended to the automotive industry in the final case study, because an opportunity presented to conduct a study in this industry and it was believed this could enrich the research by testing the model in a different context. In each of the case studies, the unit of analysis was a division or department with a specific problem to be addressed.

1.4 Brief description of the project

The project was conducted from March 1998 until February 2002. During this period, five cases studies were conducted with four collaborating companies: British Airways [2 projects], BMI British Midland International, HS Marston and the Ford Motor Company. The selection of the case studies was judgemental, based on the complexity and accessibility to the companies. Each case study involved working directly with the company on a specific project, allowing a better understanding the organisations. During these projects, different situations were analysed using a systemic approach, which helped to explain the processes and interactions that were taking place within the organisations and in relation to their environment. This analysis led to the creation of the 'Complexity-Uncertainty model'.

Figure 1 shows the evolution of the research, indicating the main stages, the logical flows between stages and the contributions to the objectives at each stage.

Figure 1: Research Process



The research process started with an analysis of the literature, as depicted in Figure 1. Then, the case studies were used to develop understanding by looking at how managers dealt with complex problems and how the change process took place. In this cyclical process, the developing model was continuously compared with the actual data supporting the process of development. The first three iterations supported the development of the model and the final two, the testing of it. This led to the creation of the Complexity – Uncertainty Model, which related to all of the case studies and could be used to support decision-making in terms of the strategies required for managing complexity.

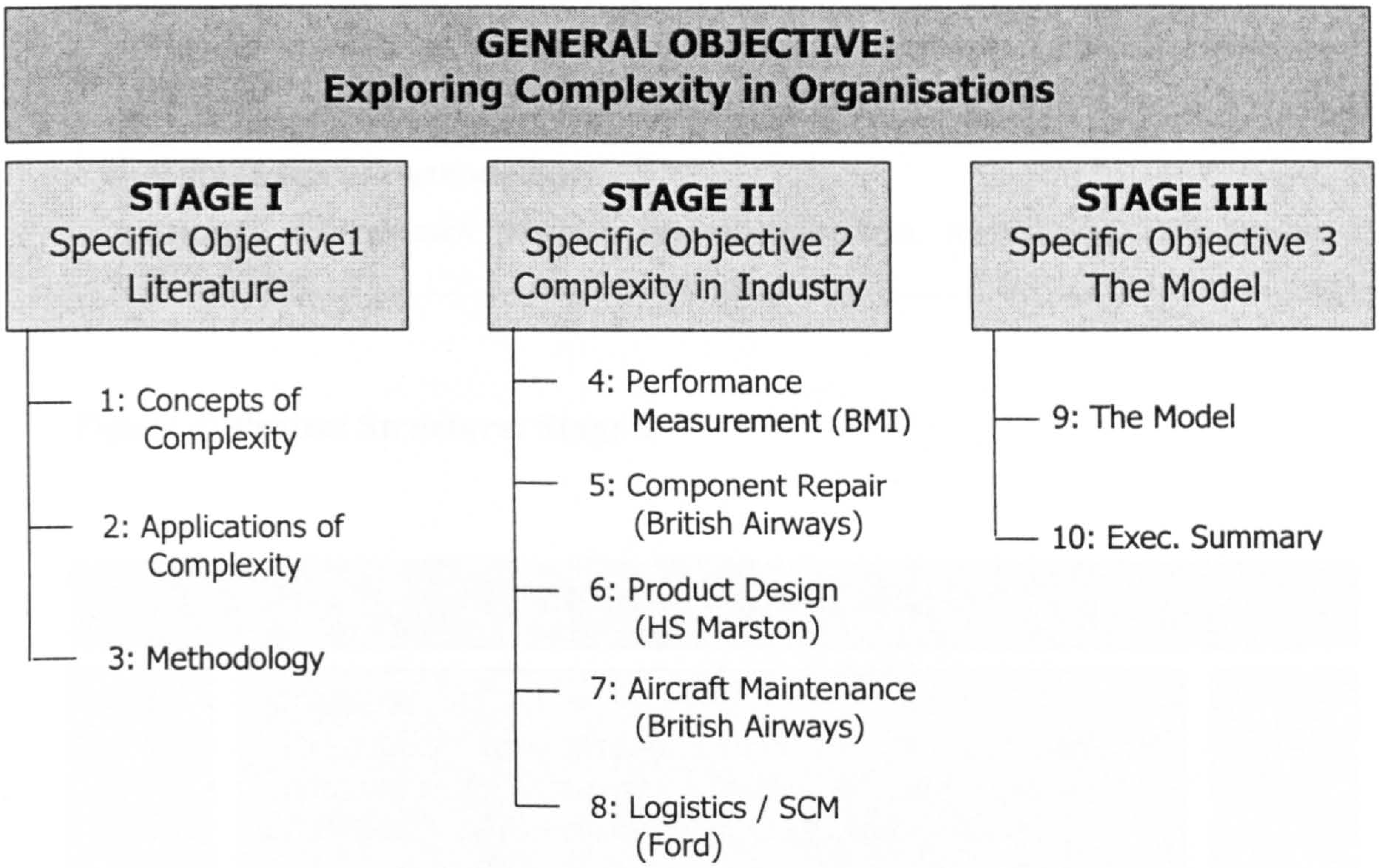
The Complexity-Uncertainty model is a descriptive and learning model that relates organisational complexity to environmental uncertainty and classifies five generic strategies that can be used in different circumstances. These strategies are automation, simplification, planning, control and self-organisation. The creation of the model and the classification of the strategies were supported both by the case studies and by the literature.

Each individual case study also contributed immediate benefits to the collaborating organisations. Examples of the contributions are: a performance measurement system developed for BMI (British Midlands), a simulation system for evaluating aircraft schedules for British Airways, the conceptual design of two components of an internet based supply chain management system for Ford, and a simulation model of the product development process for HS Marston. These contributions are described briefly in this document, and full details of the projects are presented in the corresponding submissions.

1.5 Structure of the Portfolio

The ten submissions have been structured around the specific objectives of the project, comprising three stages: an initial stage that focused on a review of the literature on Complexity, a second one which was comprised of the five case studies, and a final stage which synthesised the learning and presented the model and its conclusions. This structure is depicted in Figure 2.

Figure 2: Structure of the Portfolio



The following three diagrams present a breakdown of each of the project stages, including a description of how each submission contributed to the objectives.

Figure 3: Project Structure: Stage 1

GENERAL OBJECTIVE

STAGE I
To identify in the literature the concepts and applications of Complexity Theory that are relevant for the collaborating companies.

STAGE II

STAGE III

Submission 1: Complexity Theory: A Map of Concepts

Presents a literature review of Complexity Theory and Complex Adaptive Systems. Analyses the main concepts behind the theory and their implications for organisations.

Submission 2: Applications of Complexity: A general view

Presents a review of the current applications of complexity tools and complexity thinking in different management fields.

Submission 3: Methodology

Presents the research problem, research paradigm, methodology, and project structure.

Figure 4: Project Structure: Stage 2

GENERAL OBJECTIVE

STAGE I

STAGE II
To analyse the strategies followed by four selected companies to manage complexity, and assess the applicability of the concepts of Complexity Theory.

STAGE III

Submission 4: Complexity in Performance Measurement - BMI

A case study in collaboration with British Midlands (BMI), looking at their performance measurement system. The research analyses the implications of performance measurement and control as a strategy for managing complexity.

Submission 5: Complexity in Component Repair – British Airways

A case study focusing on the component repair process at British Airways, using time-compression approaches to streamline the processes. This case study analyses simplification as a strategy for managing complexity in organisations.

Figure 4: Project Structure: Stage 2 (Continued)

GENERAL OBJECTIVE

STAGE I | **STAGE II** | STAGE III

Submission 6: Complexity in Product Design – HS Marston

A case study in collaboration with HS Marston, a company involved in the design and manufacture of heat exchangers for the aerospace industry. Here, a simulation model based on a Genetic Algorithm is used to analyse the product development process analysing its implications for innovation, collaboration and learning.

Submission 7: Complexity in Aircraft Maintenance – British Airways

Presents a simulation model of the operation British Airways' fleet 2. The simulation is used to identify areas of improvement in the planning and scheduling of aircraft maintenance with a view to reducing uncertainty in flying schedules.

Submission 8: Complexity in Supply Networks – Ford Motor Company

A case study conducted for Ford Motor Company looking at the development of a computer system to manage the aftermarket supply network. The case study covers the analysis of the various strategies used by Ford and their business partners to manage complexity in the supply network.

Figure 5: Project Structure: Stage 3

GENERAL OBJECTIVE

STAGE I | STAGE II | **STAGE III**

To develop a model of generic strategies to manage complexity based on the case studies.

Submission 9: The Model

Presents a model for analysing organisations in terms of complexity and uncertainty. The model is based on the learning obtained from the case studies.

Submission 10: Executive Summary

Synthesises the research and presents the main conclusions and innovations of the project.

1.6 Outline of this document

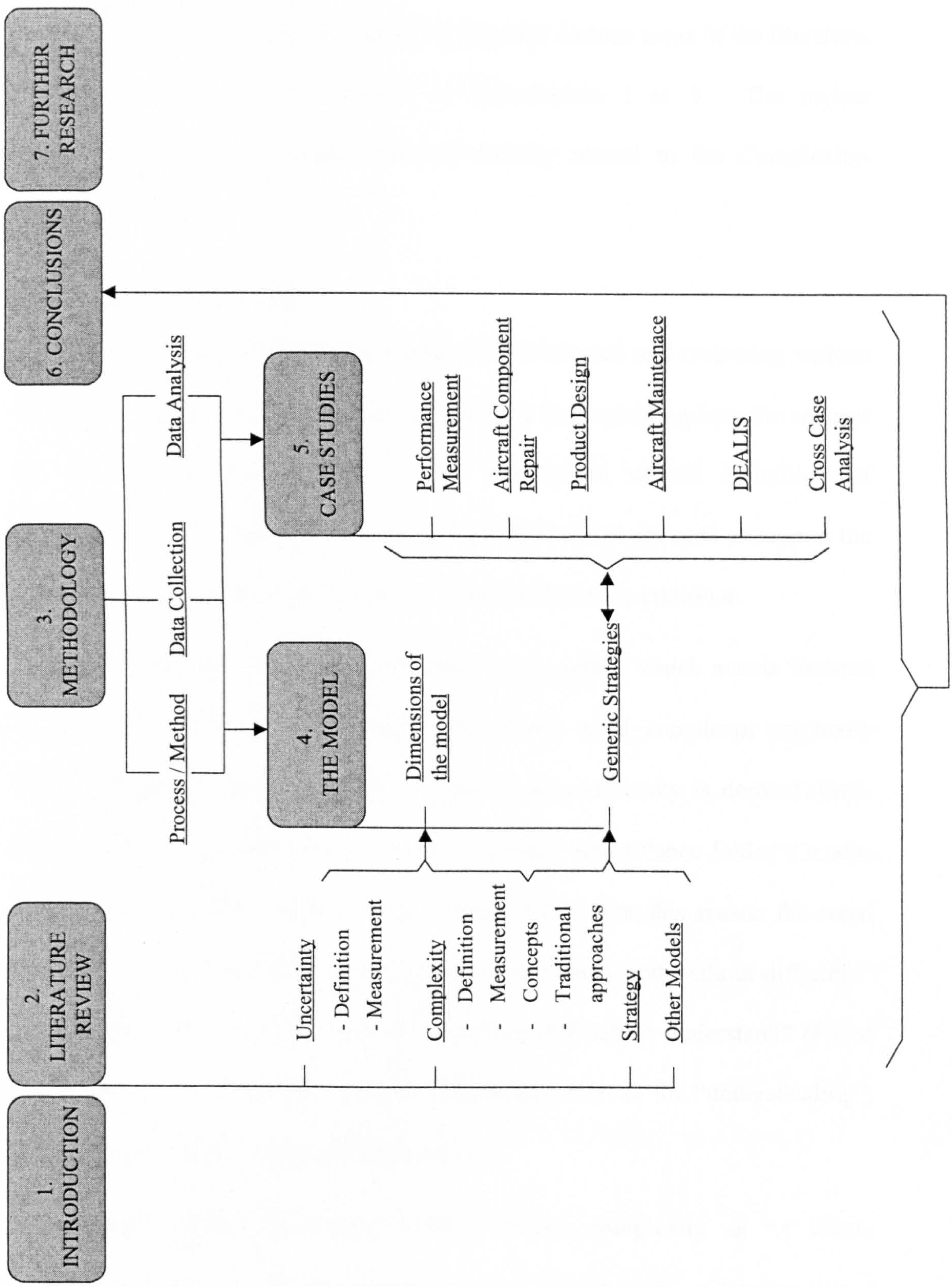
This Executive Summary has been structured as a stand-alone document, aimed at providing a clear and complete understanding of the research. It includes the most important elements of the research: a literature review, the research methodology; the description of the model and its evolution; the discussion of the case studies and the contributions to the collaborating companies.

The document is divided into seven sections, the first one being this Introduction. Section 2 presents the Literature Review, followed by the Methodology in section 3. A description of the model is presented in section 4 and the case studies, are described in section 5. The Conclusions and areas for further research are presented in section 6 and 7 respectively.

Figure 6 shows the seven chapters of this document as boxes. The four central chapters, Literature Review, Methodology, The Model and The Case Studies are broken down into their main sections, and arrows are used to indicate the key relationships between these sections. A bi-directional link between the Model and the Case Studies section indicates that both helped to shape each other in the iterative process explained earlier. For the sake of clarity in the diagram the order of some of the sections has been changed.

The structure of this document is different from the chronological order in which the research took place. The logic of the deductive process followed during the research is represented in the structure of the portfolio, where the case studies precede the description of the model. Here, the literature review is followed by a description of the model and then a review of the case studies. This allows the concepts of the model to be defined first so that they can be used in describing the case studies.

Figure 6: Structure of this document



2 Literature Review

This literature review is aimed at bringing together various areas of the literature, which have already been reviewed in Submissions 1 to 9. The review concentrates on those concepts that are directly related to the Complexity-Uncertainty model.

2.1 Defining Complexity

Complexity is one of the central concepts of this research and reviewing various definitions presented in the literature is important for explaining how the concept will be used in this research. In this sub-section, several definitions of complexity are reviewed and compared. These definitions are used to support the creation of the Complexity-Uncertainty model presented in section 4.

The term complexity is rooted in the Greek word *plektós*, which means "twisted or "braided". This term gave rise to the Latin word *complexus* originally "braided together", from which the English word complexity is derived (Gell-Mann, 1996). The Latin *simplex*, which originally meant "once folded", is also derived from the Greek *plektós* (Gell-Mann, 1996). For this reason the word simple is used as something "understood or done easily and without difficulty" (Thompson, 1996), and complex is "something difficult to understand" (Flood and Carso, 1993). However, these two definitions refer to the "understanding", leaving these terms to personal interpretation.

The Oxford English Dictionary (1989a) defines complexity as "*A whole comprehending in its compass a number of parts, (in later use) of interconnected parts or involved particulars; a complex or complicated whole*". This definition refers to the sources of complexity, in particular number of parts and interconnectedness. In Submission 1, six main sources of complexity were discussed: population, connectivity, feedback, non-linearity, asymmetry and nonholonomic constraints. This means, complexity comes from the structure (population, connectivity, asymmetry), behaviour (feedback, non-linearity) and rules that regulate the system (nonholonomic constraints). Further discussion about the sources of complexity can be found in Submission 1, Section 4.1.

The Santa Fe Institute, one of the leading research organisations in the field of Complexity Theory, has produced the following definition:

> *"Complexity refers to the condition of the universe which is integrated and yet too rich and varied for us to understand in simple common mechanistic or linear ways. We can understand many parts of the universe in these ways but the larger and more intricately related phenomena can only be understood by principles and patterns –not in detail. Complexity deals with the nature of emergence, innovation, learning and adaptation".*
>
> The Santa Fe Group, 1996

The following is another definition provided by Peter Murray (1998), who adapted an original definition by Covney and Highfield (1995) to fit an organisational environment: [Murray's comments in brackets]

> *"The study of the behaviour of macroscopic collections [like organisations] of such [basic but interactive] units [like people] that are endowed the potential to evolve over time"*
>
> Covney and Highfield, 1995 (adapted)

The key elements of complexity that can be identified from these definitions are the variety and richness in structure that cannot be understood in detail only in general patterns. It is also evident that complex systems have some particular properties, such as the ability to learn, adapt and evolve. This is, they are capable of qualitative change over time.

2.2 *The Measurement and Classification of Complexity*

Several approaches have been suggested to quantify complexity. Variety, for example, has been proposed as a measure of systemic complexity, defined as the number of distinguishable elements in a system or, by extension, the number of distinguishable systemic states (Ashby, 1965). However, to consider the many different dimensions of an organisation such as people, processes and products, and to account for all the distinguishable elements and systemic states appears to be impossible. Gell-Mann (1994) presents a classification of approaches to measuring complexity, which is discussed in Submission 1 (pp. 19-22) and are briefly summarised here:

Crude complexity: This measures the quantity of information required to describe a system, this is, the length of the shortest possible message (Cohen, et. al., 1994; Gell-Mann, 1996). This measure has some major drawbacks: firstly the quantity required to describe a system varies depending on the level of detail of the description, secondly the description is dependent on the amount of information already available, and finally the measure overlooks the fact that descriptions can be presented in many different forms.

Algorithmic information content (AIC): This measure, considers the length of the shortest program that, using a universal computer, can generate the description of the entity. This measure recognises that a description can be compressed by a program or procedure that can generate it. This approach, however, cannot cope with random behaviour, since this kind of behaviour is incompressible. Furthermore, this measure also requires assumptions about the level of detail of the description and the current knowledge available.

Effective complexity: this measure focuses on the AIC of the *regularities* of an entity, as opposed to its incidental features (Gell-Mann, 1996). A regular entity, such as a string consisting entirely of ones, will have very little effective complexity, because its regularities can be described very briefly. An entity with high effective complexity must have intermediate AIC and obey a set of rules requiring a long description.

These three measures provide different approaches to quantifying complexity. However, in every case the measurement remains context-dependent. As Casti (1997) asserts, "*complexity will always remain on the eye of the beholder*".

Another approach to measuring complexity is the use of entropic measures (Frizelle, & Woodcock, 1995; Calinescu, Efstathiou, Sivadasan, Schirn & Huaccho Huatuco, 2000). This type of measure can provide a good assessment of complexity in a stable process, where it is possible to account for the different states of the system and to assess the probability of each of these states. However, it seems extremely difficult to consider all of the possible states for an organisation and assess their probabilities. For this reason, entropic measures were not considered suitable for this research.

An alternative to a precise figure, which is considered more useful for this research, is a classification of the degree of complexity. Authors such as Beer (1967), Senge (1992), Battram (1998), Allen (1999), Glouberman and Zimmerman (2002) and Lucas (2002b) have provided a number of classifications, which are described and compared here.

Beer (1967) defines three main categories of systems, simple, complex and exceedingly complex, each divided into two levels deterministic and stochastic. Table 1 shows the six categories described by Beer along with some examples.

Table 1: Complexity of Systems (Adapted from Beer, 1967)

	Simple	Complex	Exceedingly Complex
Deterministic	Few components and, reveals a completely predictable dynamic behaviour E.g. Lay-out of a machine shop (routes & distances)	Complicated components and interrelations but deterministic E.g. An automatic factory "automation"	*Systems that exhibit deterministic chaos behaviour.* *E.g.* *Weather* *Supply Chains*
Stochastic	Few components and interrelations. Predictable. E.g. SQC (Simple system with probabilistic nature)	Highly elaborated and richly interconnected. Unpredictable. E.g. Profitability of a firm	Systems that are so complicated they cannot be described in precise and detailed fashion. E.g. (The brain, a company, the economy)

An adaptation made to Beer's model was the introduction of Exceedingly Complex Deterministic Systems. According to Beer (1967) such systems do not exist, however it is currently known that chaotic systems are deterministic and exhibit unpredictable behaviour (Gleick, 1987; Stacey, 1992; Wilding, 1998).

Glouberman and Zimmerman (2002) present a three-way classification of problems, segmenting them into simple, complicated and complex.

Simple: these are problems of basic issues of technique and terminology, but once these are mastered, the problem can be solved. Here a set of rules for solving the problem can be formulated and replicated ensuring a high degree of certainty of outcomes. An example of these would be following a recipe.

Complicated: this kind of problem is essentially a collection of simple problems which can be dealt with independently of each other. Even when each of the problems might require many different areas of expertise, there is little interdependence between them. Here rules can be followed and applied to similar problems and there is a high degree of certainty of outcome.

Complex: this kind of problem includes both complicated and simple problems, however the problem is not reducible (Glouberman et.al., 2002; Goodwin, 1994). Each complex problem is unique and experience of similar problems cannot guarantee success, hence the outcomes are inherently uncertain.

Battram (1998), based on the work of Kauffman and Langton, presents a classification of the behaviour of complex dynamic systems, defining four different classes:

- **Class I** **Stasis:** The system reaches a steady state and all the variables settle in a fixed value.
- **Class II** **Order:** The system settles down into a pattern that repeats itself.
- **Class III** **Chaos:** The system presents aperiodic behaviour but continues to have a structure in phase space.
- **Class IV** **Complexity:** This is a transition phase between periodic behaviour of Class II and the aperiodic behaviour in Class III. This is order co-existing with disorder at the edge of chaos.

Lucas (2002b) classifies complex systems in terms of their structure and behaviour into static, dynamic, evolving and self-organising. Allen (1999) uses a similar classification to define models of complex systems, and highlights the assumptions made in each kind of model. Senge (1992) uses the first two categories, static and dynamic, to describe systemic complexity. Here the four categories will be briefly described using elements from the three authors.

I. Static Complexity

This form of complexity is related to fixed systems. Here the assumption is made that the structure of the system does not change with time. This refers to quantitative aspects of the system such as size, diversity and multiplicity of hierarchical levels (Senge, 1992; Lucas, 2002b)

II. Dynamic Complexity

This type of complexity takes into account the time dimension. It refers to the causes and effects in the system and their relationships, however it makes the assumption that change in the system is cyclical, repetitive or in some way predictable. This excludes those aspects of the system that are one-off or variable (Senge, 1992; Lucas, 2002b)

III. Evolving Complexity

This class of complexity does not consider the assumption of repeatability and is used to describe systems that evolve over time, this is, it deals with open-ended change. A common example of this class is the neo-Darwinian theory of Natural Selection (Lucas, 2002b).

IV. Self-Organizing Complexity

This form of complexity combines the internal constraints of closed systems with the creative evolution of open systems (Lucas, 2002b). In this case, systems co-evolve with their environment and must be described according to their relationship to the environment. Here systems are capable of emergent behaviour, creating new structured based on their interaction (Lucas, 2002).

Several approaches to measuring complexity have been presented in this section. It has been shown that even when some measures of complexity are useful for specific applications, they are difficult to use in an organisational context and remain context-dependent. For this reason categorisation has been presented as an alternative to precise measurement of complexity and four approaches to categorising complexity have been presented. Table 2 compares these four approaches to categorising complexity, and draws a distinction between the different definitions used by the original authors. These four approaches have been used as a foundation for developing a categorisation of complexity for this research, as presented in section 4.2.1 of this document.

Table 2: Categorisations of Complexity

Author / Proponent	Beer, 1967		Glouberman & Zimmerman, 2002	Battram, 1998	Allen, 1999 Senge, 1992 Lucas, 2002
Focus	System structure and interconnectedness		**Problem structure and outcomes**	**Behaviour**	**System / Models structure and behaviour**
	Deterministic	Stochastic			
C A T E G O R I E S	**Simple**: • Few components • Predictable behaviour	**Simple** • Few components and interrelations • Predictable	**Simple** • Problems consist on basic technical issues • High degree of certainty in outcomes	**Stasis** • Steady state • Fixed value	**Static** • Fixed structure over time • Equilibrium • Events at average rates
	Complex Complicated component and interrelations	**Complex:** • Highly elaborated and interconnected Unpredictable	**Complicated** • Collection of simple problems with • Little interdependence • High degree of certainty in outcomes	**Order** • Repeatable pattern	**Dynamic** • Considers time • Change is cyclical • No micro diversity
				Complexity • Edge of chaos • Transition phase between order and chaos	**Evolving** • System evolves • Change their own net. • Open-ended change
	Exceedingly Complex • *Deterministic chaos*	**Exceedingly Complex:** • Cannot be described on precise or detailed form	**Complex**: • Includes simple and complicated problems • Not reducible • Uncertain outcomes	**Chaos** • Aperiodic behaviour with structure in state space	**Self-organising:** • Systems co-evolve in the environment • Must be described as related to the environment

2.3 Key concepts of Complexity Theory

The central concepts of Complexity Theory were described in submissions 1 and 2. This section revisits those concepts that were particularly relevant in the development of the Complexity – Uncertainty model, mainly those of feedback and non-linearity, chaos, self-organisation, co-evolution and emergence.

2.3.1 Feedback

Feedback is a process by which *information generated by an action* is used for the decision-making or regulation process, to *affect the next action* (Stacey, 1996a). Feedback is classified into positive and negative, depending on the kind of behaviour that it promotes in the system.

Negative feedback guides the system to a certain target. During the operation of the system, outcomes are compared with the target, feeding information about deviations back into the decision-making process in order to reduce these deviations (Stacey, 1996a). Positive feedback feeds back information that amplifies the outcomes of the system by creating a reinforcing loop. Examples of both positive and negative feedback are presented in Submission 1 (pp. 27-30) Positive feedback is responsible for amplifying small variations in certain variables affecting the system, making it difficult to predict future behaviour. This concept is discussed in more detail in submission 1 (pp. 31-32)

2.3.2 Chaos

In colloquial language, chaos is used to refer to disorder or confusion; however, the term is used here in a more specific way, referred to as deterministic chaos. Kaplan and Glass (1995) define it as '*aperiodic bounded dynamics in a deterministic system with sensitive dependence on initial conditions*' and Stewart (1989) as '*stochastic behaviour occurring in a deterministic system*'

These definitions refer to systems whose behaviour is based on rules, however, due to non-linear relationships, its behaviour never repeats itself and is extremely sensitive to changes. Nevertheless, behaviour in chaotic systems is still bounded within certain limits. As Stacey (1993) asserts, chaos theory '*explains that border area between stability and instability (bounded instability), where patterns are irregular and inherently unpredictable, but yet have a structure*' Chaotic behaviour has been found in many different kinds of systems such as biological, chemical, climatic, ecologic and economic (Gleick, 1987). Some researchers have also recognised that chaotic behaviour is present in the business environment (Parker & Stacey, 1994; Stacey, 1996a: Wilding, 1997; 1998). In chaotic systems, causes and effects become distant in time and space, due to the sensitivity of the system and the non-linearity of relationships. This makes the future unknowable, having significant implications for organisations.

Stacey (1993) has summarised the implications of chaos in organisations in the following points:

a) Analysis loses its primacy
b) Contingency loses its primacy (an organisation has to be both mechanistic and organic)
c) Long term planning becomes impossible
d) Visions become illusions
e) Consensus and strong cultures become dangerous
f) Contradiction, conflict, dialectics and learning become essential
g) Statistical relationships become doubtful
h) Probability helps only in the short term
i) Long term forecasts and simulations are impossible
j) Requisite variety loses its usefulness: changes are unique not repetitive and small changes do escalate to large consequences

One of the most important areas within management where Chaos Theory has implications is in the field of strategy formation. Section 2.5.3.1, presents a detailed discussion in this subject.

The concepts of feedback, non-linearity and chaos have contributed to the development of the Complexity – Uncertainty model because they help to explain the limitations of two of the generic strategies, Control and Planning. These limitations are discussed in detail in sections 4.3.3 and 4.3.4 respectively.

2.3.3 Self-organisation

The concept of self-organisation had a central contribution to the development of the Complexity- Uncertainty model, as it consolidated as one of the generic strategies of the model. For this reason it was decided to review this concept in more detail than the other concepts presented in this section. A discussion on how self-organisation fits into the Complexity-Uncertainty model is presented in section 4.4.5

The concept of self-organisation has evolved over time and has been applied in different fields of research (Krohn, Kuppers and Novotny, 1990). This makes it difficult to encapsulate the concept in a single definition.

Krohn, Kuppers and Novotny (1990) trace the concept of self-organisation to Kant's "Critique of Judgement" (1790), referring to the capacity of parts or organs of producing other parts, each, consequently reciprocally producing others. Another early reference is from Farey and Clark in 1954 (Heylighen, 1997a) who define a self-organising system as one which changes its basic structure as a function of its experience and environment. Von Foerester (1960) argues that an organism organises itself independently of its environment and Ashby (1960) redefines self-organisation as a process that consists of the organism and its environment taken together. Some other authors such as Heylighen (1997b) and Lucas (2002a) define it as a process of evolution in which the involvement from the environment is minimal. In self-organisation, evolution is triggered by internal variation processes, usually called fluctuations or noise (Heylighen; 1997a). For Casti (1997) self-organisation is a property of complex systems that explains how systems without central control tend to settle down into just a few states even when, theoretically, the number of possible states is almost infinite, suggesting that the interaction of the elements of the system creates some kind of *order.*

During the 1960's, the subject of self-organisation was explored from different perspectives. Heinz von Foerester (1960) looked at if from an information theory perspective. Herman Haken (1983) also explored in the context of laser theory, and Ilya Prigogine in the field of thermodynamics (Prigogine, 1976). Prigogine's research shows that when a thermodynamic system is driven *far from this equilibrium*, by pumping energy, it will reach a threshold above which it can exhibit "self-organisation", at this stage, the systems become *dissipative structures* (Prigogine, 1976)

According to Prigogine (1976) self-organisation is not restricted to thermodynamic systems, examples of a similar type of order emerging from the interaction of the elements of the system can be found in chemical, biological and even social systems. All these appear to have some order despite the high complexity of the systems in which they interact. Some commonly used examples of self-organisation are lasers, Bernard cells, cellular autocatalysis, birds flocking, brains, ecosystems and economies (Lucas, 2002)

Self-organisation is usually associated with non-linearity that results from the interaction of positive and negative feedback cycles, where some variations reinforce themselves, while others mitigate themselves. This interaction can lead to unpredictable patterns, which can develop very quickly until they reach a stable configuration (an attractor) (Heylighen, 1997a).

Lucas (2002) has identified a number of typical features of a self-organising system, which are helpful for characterising this phenomenon:

- Absence of centralised control
- Fluctuations (searches through options)
- Multiple *equilibria* (possible attractors)
- Global order (emergence from local interactions)
- Redundancy (insensitive to damage)
- Adaptation (stability to external variation)
- Hierarchies (multiple self-organized levels)
- Dynamic operation (time evolution)
- Symmetry breaking (loss of freedom)
- Criticality (threshold effect phase changes)
- Self-maintenance (repair & part replacement)
- Dissipation (energy usage and export)
- Complexity (multiple parameters)

Self-organisation relates to order creation and innovation and therefore it is very appealing to the study and practice of management. As Stacey (1995) maintains, in order to innovate, '*managers rely on self-organizing political and organizational learning processes to produce an emerging unfolding but unpredictable future*'. Other authors such as Wheatley (1994), Coleman (1999), Anderson (1999) and Clippinger (1999) have explored and supported views about self-organisation in a business environment.

Some authors define self-organisation in the business context in terms of its enablers. Coleman (1999), for example, defines it as simply "*a process of human motivation enabled by empowerment practices*", where self-organisation takes place when people are free to network and follow their own objectives.

Bonabeau & Mayer (2001) claim that self-organisation takes place when a group has little supervision or top down control, and Pascale (2001) considers that it is a property that emerges from intelligence in the remote clusters of a network which are able to generate novel patterns. All these definitions appear to be consistent with some of the characteristics of self-organising systems in nature such as absence of centralised control, fluctuation and emergence from local interaction. However, they only provide a partial picture.

A more complete definition provided by Stacey (1993) defines self-organisation in a management context as "*the spontaneous formation of interest groups and coalitions around specific issues, communication about those issues, cooperation and the formation of consensus on and a commitment to a response to those issues*". According to Stacey (1992), the conflict, instability and lack of consensus produced by a multiplicity of cultures is what provokes the system to innovate. Self-organisation can produce order in the form of '*innovation and new strategic direction out of chaos*' (Stacey, 1992). Stacey (1992) also suggests two mechanisms that allow self-organisation to take place: group learning and political interaction.

Based on the concept of self-organisation, a number of authors have suggested a need for changes in the role of managers (Anderson, 1999; Clippinger, 1999; Stacey, 1992). The call for freedom and decentralised control does not mean that managers are not necessary anymore; it simply means that no central control is necessary (Anderson, 1999). Based on the work of Stacey (1992), Anderson (1999) and Clippinger (1999) it is possible to list a series of factors suggesting what self-organisation means (and does not mean) for management:

- Managers create the environment for establishing self-organising learning teams through self-selection and challenge. They also influence how widespread learning is and what quality it takes.
- Managers influence the learning and political processes in the organisation
- Managers commit to guiding the evolution of behaviours
- Managers are responsible for maintaining the boundaries.
- Managers do not engineer solutions, workers do
- Managers intervene indirectly by shaping the environment
- It means that effective behaviour emerges from the interaction of independent agents not from standards and plans defined by managers
- It does not mean letting people do whatever they want to do
- It does not imply that managers are passive
- It means that managers have no control over self-organising networks

Self-organisation presents an alternative way of achieving order, which applies not only to natural systems but also to management systems. This is important for the development of the model because it presents a way of dealing with uncertainty that does not relate to traditional ways of simplification and control.

2.3.4 Co-evolution

Co-evolution is the result of the interaction of systems where the actions of one system affect another. Kauffman (1993) asserts that co-evolution is similar to adaptation, but in this case, the system never reaches equilibrium and continues to develop, striving for progress in terms of profitability, growth or sustainability.

From an ecology perspective, co-evolution has been defined as '*the interdependent evolution of "species" that interact "ecologically". The interactions may be antagonistic (consumer-resource) or cooperative (mutualism). Because each "species" in the coevolved pair is an important* *component of the environment of the other, changes in one select adaptive responses in the other, and vice versa* (Ricklefs, 1990).

Co-evolution can be found in a range of systems from an ecosystem, where species change as they interact with one another, through to strategies in a game where in theory the players are co-evolving with each other (Holland, 1998).

In a co-evolutionary process, according to Kauffman (1993), the parameters for measuring the success of the system are continuously changing, so that the fitness landscape is deformed, altering the fitness value of peaks and valleys. This is one of the reasons for the prediction of future states being virtually impossible, making emergent properties evermore important.

A more detailed description of the concepts of co-evolution and fitness landscapes is presented in Submission 1 (pp. 40 – 43).

2.3.5 Emergence

This concept of Emergence was introduced in Submission 1 (pp. 36 –38), where a discussion, along with a number of examples from different fields of research, is presented. Emergence refers to those properties of a system which are beyond the properties of any of its components (O'Connor et. al., 1997). These are known as emergent properties — they emerge from the system when it is operating (O'Connor et. al., 1997). Emergence embodies the idea that "the whole is greater than the sum of its parts".

The concept of emergence challenges the idea that systems can be fully analysed by breaking them into its individual components. Emergent properties cannot be predicted and can only be understood using a holistic approach (Lucas, 2003).

According to Lucas (2003), '*this is a feature of open-ended evolution - novelty appears outside our current experience or that of the system*'.

Holland (1998) points out that when agents co-evolve and self-organise they create new and emergent patterns which would be '*next to impossible' to predict'* even if all the initial strategies and the individual learning procedures were known from the outset.

The concept emergence is important for this research because it explains the spontaneous innovation that results from self-organisation and co-evolution. As it will be discussed later, this innovation is critical for organisations in an uncertain environment.

2.4 Traditional approaches to dealing with complexity

In organisations, managers have always had to deal with complexity. Usually strategies have been focused on eliminating and controlling complexity. For example, Handfield (1995) and Gregory and Rawling (1997) have developed classifications of the main strategies for dealing with complexity in processes identifying strategies such as those of control, simplification and automation. For this research, these approaches have been called 'traditional', since they are not related to Complexity Theory. A number of these traditional approaches have been identified and are discussed in detail in Submission 9 (pp. 15-36). In the following subsections, these strategies will be described based on the discussion presented in Submission 9.

2.4.1 Simplification

Simplification is defined by Gregory and Rawling (1997) as strategy concerned with removal of the sources of complexity and waste in organisations. Simplification as a strategy for organisations can be traced back to authors such as Adam Smith (1776) and Frederick Taylor (1911), among others, who supported approaches such as the division of labour and time & motion studies. These approaches tended to focus on finding the simplest and most efficient way of performing individual tasks. More recent approaches to simplification have broadened the scope from individual tasks to complete processes.

There are many management approaches centred on the elimination of complexity, such as Value Engineering (DeMarle & Shilito, 1992), Business Process Re-engineering (BPR) (Hammer & Champy, 1993), Time Compression (Stalk and Hout, 1990; Gregory, et. al, 1997), Lean Production (Womack & Jones, 1996) and Just-in-Time (Shingo, 1989).

The benefits of simplification have been researched and discussed by a number of authors (Rommel, et. al. 1995, Shomberger, 1986, 1982; Peters & Waterman, 1982). Shomberger (1986, 1982) identifies simplicity as one of the key success factors of Japanese industry during the 70's and 80's. Similarly, Rommel (et. al., 1995) highlights simplicity as the key for the success of the German machinery manufacturing industry during the 1990's.

Simplification has been proved to have many benefits but also limitations. These limitations reside on the fact that it assumes that processes can be isolated, fully understood and centrally designed. However, most processes have more states and interactions than those that can be analysed, and this causes a risk of oversimplification.

2.4.2 Automation

Automation is the substitution of human physical and mental work by the work of machines (Cox, et. al., 1992). This strategy can be effective for simple and repetitive activities, however, for complex processes, automation might prove to be very difficult to implement. Moreover, in an uncertain environment in which technologies are changing and demand is volatile, the investment required to automate a system might be difficult to justify (Talavage & Hannam, 1992).

Automation has been applied to manufacturing processes with technologies such as Computer Numerically Controlled Machines (CNC), Robots and Flexible Manufacturing Systems (FMS). In most service organisations the main enabler of automation is Information Technology (IT), taking advantage of the ability of computers to transmit data and perform calculations.

The main limitation of automation is that it does not have the flexibility and ability to learn and adapt that humans have. Replacing people with machines creates systems with less internal complexity, which might not be able to cope with changes in the environment.

According to Shomberger (1986), the main advantage that equipment has over people is to decrease variability: uniform motions, uniform cycle times, and uniform quality. This reduction in variability can be effective only if the organisation needs to standardise its processes and products, that is, if there is excess complexity in the system. However, if there were no excess complexity in the organisation, automating processes would only decrease the ability of the organisation to adapt to changes in its environment. According to Rommel (et. al. 1995), trying to automate a process in an uncertain environment can lead to an unstable process causing considerable disruption to the system as a whole.

2.4.3 Control

Control has been defined in many different ways. Henry Fayol (1949) defined it as a critical stage in the management process that helps to ensure that everything occurs in conformity with policy and practice. The Cybernetics/Systems approach defines it as a process to maintain a system within certain limits using feedback (Flood, 1999). Buchanan and Huczynski (1991) follow an organisational behaviour perspective and define management control, as "*the process through which plans are implemented and objectives are achieved by setting standards, measuring performance comparing actual performance and then deciding necessary corrective action and feedback*"

Buchanan and Huczynski (1991) argue that the concept of control in organisations has many different connotations. It can mean predictability, order and stability, which they believe to be a positive connotation since it provides people with a degree of order and predictability in their lives. However, control can also mean coercion, domination, exploitation and manipulation, and from this perspective, the absence of control means freedom, individuality, discretion responsibility and autonomy.

Galbraith (1973) defines three forms of control, which he associates with the mechanistic model (Burns & Stalker, 1961). These forms are:

a. **Rules, Programs, Procedures**: this approach specifies the necessary behaviours in advance of their execution. This is the simplest form of coordination between interdependent subtasks.

b. **Hierarchy**: managerial roles are used to deal with situations that have not been encountered before and therefore there are no roles to deal with them. Managers handle the information collection and decision making tasks required by uncertainty.

c. **Target or Goal Setting**: brings the points of decision making down to the point of action where information originates, increasing the amounts of discretion by employees at lower levels of the organisation. Targets or goals are used to coordinate interdependent subtasks while allowing discretion at a local subtask level.

Galbraith (1973) recognises that when uncertainty increases, the hierarchy is overloaded and these approaches to control are not sufficient. He defines another four strategies for situations of increasing uncertainty: creating slack resources, creating self-contained tasks, investing in vertical information systems and the creation of lateral relations. These strategies for managing increasing uncertainty suggested by Galbraith in 1973, appear to be aligned to some of the concepts of Complexity Theory, such as interconnectedness and the use of slack resources.

Drucker (1974) suggests that complexity in organisations limits the ability to control it. The main reasons that he provides as evidence for this are the difficulties in measuring human systems, the multiplicity of objectives, causes and effects in organisations, the value-setting character of control mechanisms and the uncertainty of responses the control systems can provoke. Along similar lines, Lawler (1976) identified three human problems created by control in organisations. Firstly, misplaced controls lead to rigid bureaucratic behaviour, where people behave in order to satisfy the controls and not necessarily to benefit the organisation. Secondly, controls promote distortions in the measurement process and thirdly, controls may be seen as a threat and therefore resisted by people in the organisation.

Stacey believes that control in organisations is paradoxical since it is required both to maintain the system in equilibrium and to allow it to be flexible and innovative (Stacey, 1993). He classifies control into three main approaches, each of which can be used in different situations.

a) **Planning and Monitoring form of control:** This form of control, suitable for situations of closed change, is based on negative feedback intended to bring the system to stability. This approach is constrained by organisational intention and is effective only in the short-term. In the long-term, using this approach is only a 'fantasy defence to protect managers against the anxiety that uncertainty and ambiguity generate' (Stacey, 1993).

b) **Ideological form of control:** This form of control, maintained by political and learning feedback loops. Control by intuition and judgement is based on the mental models that managers are using and their learning process. Here, managers use visions, missions, values and ideologies to maintain the system under control. However, when uncertainty is high, the possibility of applying power diminishes and anxiety takes over, for this reason Stacey (1993) believes that this form of control is suitable for closed and contained change situations only.

c) **Self-organising forms of control:** This form of control relies on both positive and negative feedback, and it is suitable for situations of high uncertainty, this is, situations of open-ended change. In this form of control, '*people interact spontaneously forming a system that is self-organising and that their behaviour is amplified leading to overt and covert political actions, unconscious processes, organisational defences and the questioning of shared mental models*' (Stacey, 1993). Self-organising can be considered as a form of control firstly because, in the same way as the other two forms of control, it uses feedback connections between discovery, choice and action, and secondly because it provides boundaries around the behaviour of the system (Stacey 1992, 1993).

According to Stacey (1993), in the self-organising form of control the role of top managers is different from that in stable situations. Here managers do not plan or create ideologies, but they are responsible for influencing the learning and political processes in the organisation. In this case, managers do not have central control over choices and outcomes but can determine how learning takes place and is disseminated within the organisation.

Most definitions and approaches to control are restricted to the planning and monitoring, and ideological forms of control. However, as Stacey clearly states these approaches are only effective in situations of closed or contained change. This clearly sets the limits to these forms of control.

2.5 Perspectives on Strategy

Strategy formation has been a widely debated subject for at least 40 years. Over this period, several schools of thought have emerged, representing different perspectives on strategy. Several authors have classified and compared the different schools (Segal-Horn, 1998; Mintzberg, 1998; Van der Heijden, 1996; Whittington, 1993; Taylor, 1987). Two such classifications, developed by Mintzberg (1998) and Taylor (1987), are presented in Submission 9 (pp. 27-28). The schools range from the mechanistic –analytical processes based on planning and monitoring– to the unstructured mental processes searching for innovation and adaptation.

According to Mintzberg (1998) the more prescriptive and analytical approaches were in vogue in the 1960's and 70's, while during the 1980's and 90's descriptive approaches became more popular. Segal-Horn (1998) holds a similar view, stating that there has been a gradual evolution of strategic management away from rational planning and towards an emergent and incremental view.

2.5.1 The planning perspective

Planning is a controversial subject that has been defined and interpreted in many different ways. Mintzberg (1981) argues that there is a lack of clarity about the meaning of planning and he explores and criticises different approaches to defining it. He classifies definitions of planning into the following categories:

- *Planning as future thinking*: this is simply taking the future into consideration. However, Mintzberg argues that all decision-making deals with the future and hence this definition makes the two terms indistinguishable.
- *Planning as integrated decision-making*: this refers to a conscious attempt to integrate decisions across different areas. Mintzberg believes that this

definition lacks specificity because it could also include the entrepreneurial process of visioning and decision-making as a form of planning.

- *Planning as formalised procedure and articulated result:* refers to a systematic, explicit, recoverable thought process', helping to analyse information and feeding it to decision making processes. However, Mintzberg argues that this falls short of an operational definition because it defines intentions and not actions.
- *Planning as programming:* here planning is not used to develop the intended strategy but to elaborate on the consequences of an intended strategy already conceived.

Mintzberg (1981) argues that the last two definitions (i.e. Formalised procedures and programming) are the ones that reflect what planners in organisations actually do. He then concludes that planning takes a role, not at the centre of the strategy process, but at either side; first feeding the information necessary for decision making and then codifying, elaborating and converting intended strategy. Mintzberg (1994a, 1994b, 1994c) has been critical of the concept of strategic planning, arguing that it is more formalised thinking about strategy than strategic thinking. However, Mintzberg also accepts that planning is necessary in certain situations to coordinate human and other resources.

The view that planning does not develop strategy is shared by a number of authors and, in fact it is one of the arguments presented by some proponents of Complexity theory in organisations as is described in the following section.

There are also several authors who actively support planning as a key element of strategy formation (Ansoff, 1991; Porter, 1996; Gaddis, 1997). Ansoff (1991) directly contradicts Mintzberg, by stating that his definition of planning is different from that used in practice and arguing that there is observable evidence that planning works. Porter (1996) accepts that there are limitations to planning, however he argues that it is essential that a company try to 'extend its uniqueness while strengthening the fit among its activities'. Gaddis (1997) also acknowledges the limitations of planning but asserts that managers and boards still need to demonstrate purposefulness in their plans and the best way of doing this is through gaining a better understanding of their organisation and its environment.

The suitability of different approaches to planning depends on the scale and scope of the plan as well as on the complexity and uncertainty of the situation. For example, mechanistic approaches to planning might be suitable for relatively stable and progressive situations, but ineffective in situations of high uncertainty. Other approaches, such as scenario planning, are bound to be more effective in situations of increasing uncertainty.

Planning is outward looking, as it tries to understand the environment and guide the organisation towards a desired future. However, planning has its limitations as, even when some repetitive patterns are predictable inside and outside the organisation, forecasting discontinuities, such as technological innovation or price increases, is virtually impossible (Mintzberg, 1994a). This does not invalidate the need for planning; according to de Geus (1997), "*the real purpose of effective planning is not to make plans but to change the... mental models that... decision makers carry in their heads*". This view considers planning as a learning process rather than an aid to control.

Planning is one of the strategies in the Complexity-Uncertainty model. The model indicates how planning can support organisations in dealing with complexity and uncertainty, and it acknowledges its limitations. Section 4.3.4 describes in more detail how this strategy fits into the model.

2.5.2 The Complexity Perspective to Strategy Formation

Complexity Theory has presented the strategic management field with a new perspective which has attracted increasing attention since the early 1990's. The Complexity perspective inclines towards the emergent and incremental view of strategy formation, similar to other contemporary schools, but its core concepts have their origins in scientific discoveries from the study of Complex Adaptive Systems in nature. This section presents a critical review of the Complexity Theory perspective of strategy formation, contrasting and comparing the views provided by different authors.

During the 1980's and early 1990's a number of books popularised the scientific discoveries of Chaos (Gleick, 1987) and Complexity (Waldrop, 1993; Lewin, 1993; Cohen & Stewart, 1994, Casti, 1995). These publications stimulated researchers and practitioners to think about how these theories could be applied to organisations. As a result, the last ten years have seen a surge in management literature related to Complexity Theory and its application to organisations, particularly the subject of strategy formation.

Figures 6 and 7 show the sequence of publications in the application of Complexity to Strategy formation; Figure 6 focuses on academic papers and Figure 7 on books published. These diagrams show clearly that Complexity and its role in strategy formation started to attract attention in the late 1980's and early 1990's and that this attention has continued to grow since then.

Figure 7: Timeline of Complexity and Strategy Publications (Papers)

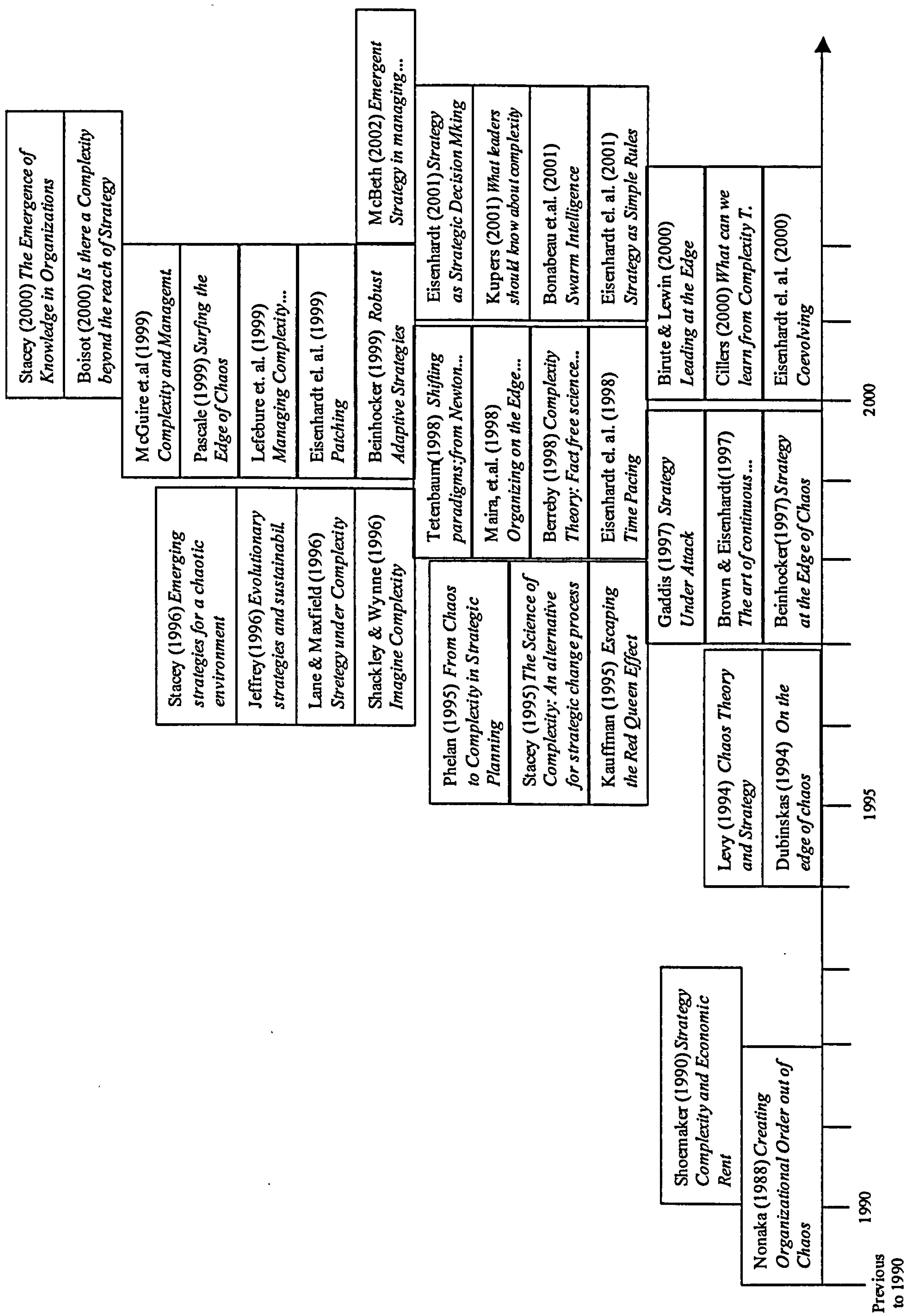
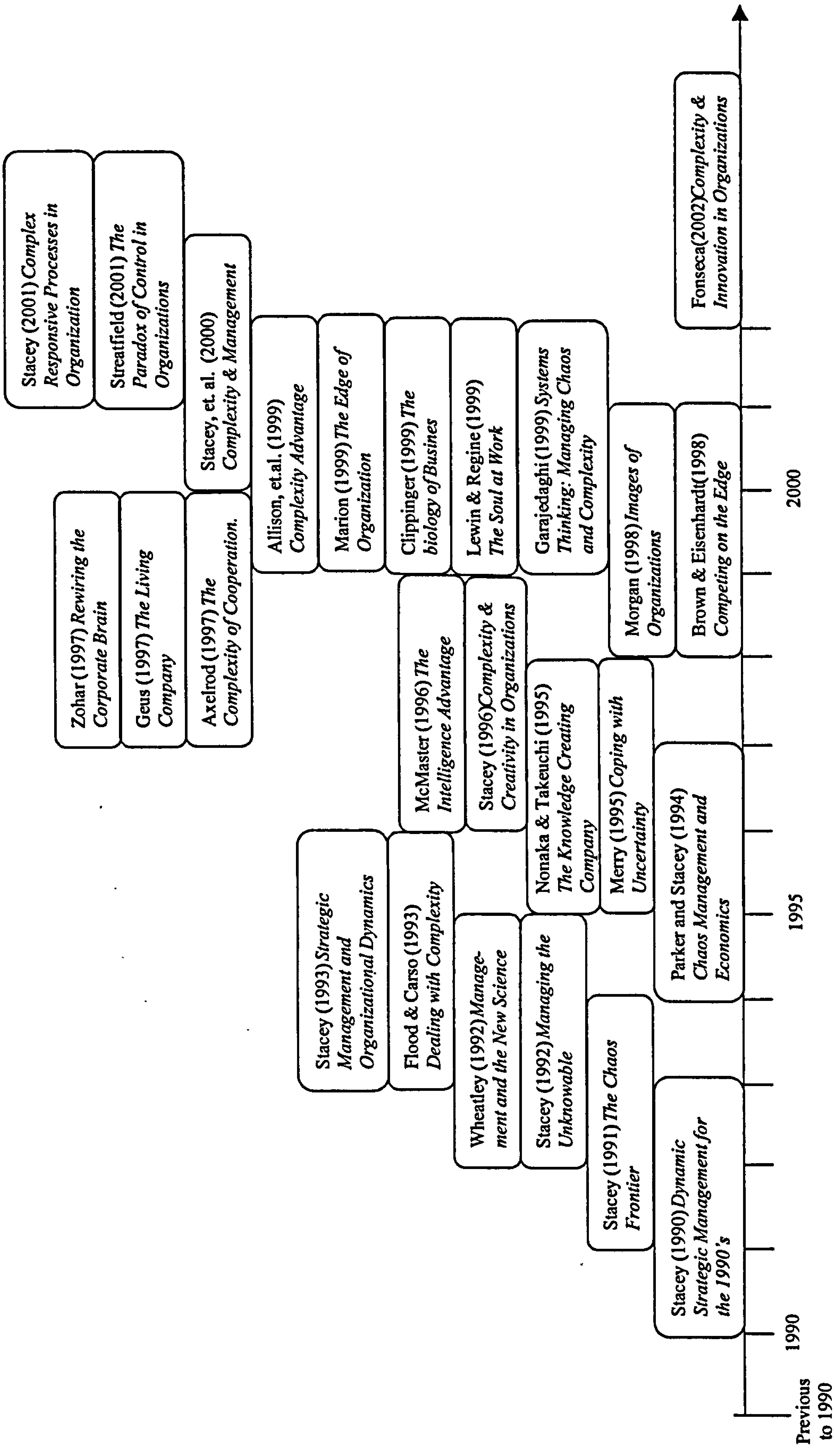


Figure 8: Timeline of Complexity and Strategy Publications (Books)



2.5.3 Views on Complexity and Strategy

The available literature in complexity and strategy reveals a number of views of and alternatives paths to the application of the concepts of complexity. This section analyses these different views, breaking them down into four categories:

1) **Consistent:** those views that are shared by the majority of the authors in the field, forming a generally accepted view of the role of Complexity in strategy formation.
2) **Complementary:** those views that, although they might not have been widely discussed by a range of authors, are aligned to the concepts of Complexity and complement existing views.
3) **Conflicting:** those views where some of the ideas proposed create conflict but where the essence of the concepts of Complexity is retained.
4) **Contradictory:** those views which radically oppose to the application of Complexity theory in the field of strategy and oppose its core concepts.

2.5.3.1 Consistent views

In this category, the views of most authors in the field coincide. This consensus is centred on a series of propositions, based on the concepts of Chaos and Complexity, which challenge traditional views of strategy. The term "traditional view" is a generalisation of a widely accepted view on strategy, but which does not necessarily cover all of the different schools of thought and approaches to strategy formation. The generalisation is used here to contrast views about Complexity with the more conventional interpretations of strategy.

These propositions of Complexity theory applied to strategy can be expressed as dichotomies or paradoxes, contrasting the Complexity view with the traditional view. Six of these paradoxes can be considered as common among most authors:

a) Order vs. Chaos

Traditional perspectives on strategy assume a system in a state of stability and closed change, where the past is understandable and the future is predictable (Nonaka, 1988; Stacey, 1992, 1993; Beinhocker, 1997, 1999). Such an ordered system can be reduced and analysed by decomposition. In contrast, the complexity perspective suggests that ordered systems are rare and short lived and that most organisations are systems in a state of bounded instability (Stacey, 1992, 1993). This view of organisations presumes that the system is in constant flux with periods of temporary stability, and it rejects mechanistic and positivistic approaches to understanding human behaviour and acknowledges the complexity and diversity of experience (Nonaka, 1988, Levy, 1994; Dubinskas, 1994; Wilding, 1997)

b) Equilibrium vs. Far-from Equilibrium

Ikujiro Nonaka (1988), one of the first authors to recognise the importance of Chaos theory in strategy formation, argues that traditional management theories place emphasis on maintaining order and equilibrium by applying control mechanisms at a strategic management level. He claims that models focusing on the roles of ambiguity and chaos should be developed. This view is shared by a number of other authors such as Stacey (1992, 1993), Beinhocker, (1997, 1999), Pascale (1999, 2001), and Brown & Eisenhardt (1997).

The complexity view suggests that for a system to be creative and able to renew itself, it needs to be at a state far from equilibrium (Stacey, 1992; Nonaka, 1988). In this state, also termed the Edge of Chaos (Kauffman, 1995), the organisation is able to innovate and adapt to change (Beinhocker, 1997; Brown et. al. 1997).

c) Linear vs. Non-linear Causal Relationships

Traditional views assume that relationships in organisations are mainly linear, and hence it is possible to extrapolate current patterns into the future, making it predictable. The Complexity view suggests that the main reason for the unknowable character of organisations is that they are non-linear feedback systems and exhibit chaos.

Chaos refers to types of behaviour which are an 'intricate mixture of order and disorder, regularity and irregularity, but are nevertheless recognisable as broad categories of behaviour' (Parker & Stacey, 1994). In a chaotic system, causes and effects are distant in time and space and the system exhibits synergy. Hence, the analysis of such a system by decomposition is not possible (Parker & Stacey, 1994; Stacey, 1996a). Furthermore, chaotic systems are highly sensitive to initial conditions so minor variations in current conditions can produce large fluctuations in the future. In Non-linear feedback systems, the long-term future is inherently unpredictable and reductionist or causal tools tend to be ineffective (Peitgen, Jurgens & Saupe, 1992, Parker & Stacey, 1994; Dubinskas, 1994; Stacey, 1996a, Wilding, 1997). Dubinskas (1994), using an ethnographic example of a manufacturing automation project, concludes that 'no mechanistic causal model can adequately account for the complexity, indeterminacy and unpredictability of the project's outcomes'.

d) Predictability vs. Uncertainty

Traditional views on strategy make the assumption that the future is predictable and that long-term forecasts can have sufficient accuracy to be able to commit to a focused plan. However, feedback and non-linearity make the future difficult to predict and in certain aspects unknowable (Parker & Stacey, 1994; Stacey, 1996a, Wilding, 1997). Levy (1994), using a simulation of a supply chain, concluded that in chaotic systems, whilst it might be possible to produce short-term predictions, long-term forecasting and planning is almost impossible and that dramatic change can occur unexpectedly.

Stacey (1992) argues that conventional management approaches are not suitable in a continuously changing environment. He states that when the future is knowable, it is possible to analyse problems and identify solutions using a systematic and formalised process. Even when the future is unknown it is possible to conduct research to gather information and perform analysis. However, when the future is unknowable it is not possible to apply analytic tools in the creation of strategy. This calls for a different approach to strategy formation which emphasises, innovation, learning, diversity and adaptation, rather than planning and control.

e) Control vs. Self-organisation

The traditional approach to planning and control is grounded in the principle of negative feedback; this means intervening in the system in order to reduce or eliminate variations from a predetermined target. This is usually done as a centralised process, where top managers create plans and targets and then apply control mechanisms in an attempt to achieve their plans. An alternative proposed by the complexity approach is control through self-organisation. In self-organisation, the system is maintained within boundaries, through a combination of positive and negative feedback (Stacey, 1992; 1993). Self-organisation is based on decentralised networks of individuals who empower themselves and create new patterns and mental models through learning and political dialogue

(Nonaka, 1988; Stacey, 1992, 1993; Pascale 1999, 2001; Anderson, 1999; Bonabeau & Meyer, 2001; Coleman, 1999).

Self-organisation, according to Nonaka (1988), creates order through physical and mental patterns. This means the creation of information and mental models for interpreting information. This is done by teams with three characteristics: autonomy, multidisciplinary and challenging goals (Nonaka, 1988).

In self-organisation 'people interact spontaneously forming a system that is self-organising and that their behaviour is amplified leading to overt and covert political actions, unconscious processes, organisational defences and the questioning of shared mental models' (Stacey, 1993). Self-organisation can be considered controlled behaviour because, like other forms of control, it uses feedback connections between discovery, choice and action, and because it provides boundaries around the behaviour of the system (Stacey 1992, 1993). In the self-organising form of control, the role of top managers is not to plan or create ideologies, but to influence the learning and political processes in the organisation. Here, managers do not have central control over choices and outcomes but can determine how learning takes place and is disseminated within the organisation (Stacey 1992, 1993).

Nonaka (1998) emphasises the importance of self-organisation through fluctuation, in order to create "order out of chaos". However, Nonaka and Takeuchi (1995) recognise that fluctuations are not the only elements of creative Chaos. They highlight the following factors:

- *Intention*, the organisation's aspirations and goals,
- *Autonomy,* the individual freedom to introduce unexpected opportunities

- *Redundancy,* the use of redundant information and communication to speed up the knowledge creation process, and
- *Requisite variety*, the matching of the organisation's internal variety with the variety in the environment, to deal with external challenges.

f) Sustainable Advantage vs. Continuous Adaptation

Beinhocker (1997) points out that traditional views of strategy and many common strategy tools such as the five forces framework (Porter, 1985) and the concept of sustainable competitive advantage (Porter, 1985) and cost curves are rooted in neoclassical microeconomics, which in turn was derived from energy physics and thermodynamics. This traditional view of strategic planning portrays organisations as systems in search of equilibrium and emphasises a single focused approach to competition (Stacey, 1992; Nonaka, 1988, Brown et. al. 1997). Beinhocker (1997; 1999) argues that equilibrium-based strategy tools prepare organisations to be competitors but not evolvers although organisations should seek to be both. The Complexity view proposes that competitive advantage cannot be sustained for any significant period and that organisations should look for new alternatives that can provide a temporary competitive edge, rather than an attempt to protect their current competitive advantage.

Beinhocker (1999) affirms that long-term superior performance is achieved, not through sustainable competitive advantage but by continuous development and adaptation of new sources of temporary advantage. Along similar lines Levy (1994) suggests that in order to cope with complexity and uncertainty it is necessary to have broad strategies that can be adapted to the environment.

Table 3 summarises the dichotomies contrasting the Complexity and the traditional view of strategy.

Table 3: Traditional vs. Complexity views of Strategy

	Traditional View	Complexity View
Nature of Change	**Order:** assumes the organisation and its environment remain relatively stable for long periods of time	**Chaos:** organisations are chaotic systems in a state of bounded instability. They are in constant flux
Assumptions about Equilibrium	**Equilibrium:** management focuses on maintaining order are reaching equilibrium	**Far-from equilibrium:** in order to renew themselves systems need to be far from equilibrium
Causal Relationships	**Linear:** cause-effect relationships are linear	**Non-linear:** relationships are non-linear, making the future unpredictable
Degree of Predictability	**Predictability:** The future of the system can be predicted with reasonable accuracy	**Uncertainty:** the future is uncertain or unknowable.
Source of Order	**Control** through negative feedback is used to maintain order and coherence in the organisation.	**Self-organisation** is the source of order and creativity in the organisation (through positive and negative feedback)
Competitive Advantage	**Sustainable:** the sources of competitive advantage in organisations are sustainable	**Continuous adaptation:** organisations have to keep looking for new sources of temporary competitive advantage.

Some of these apparent contradictions were useful in the development of the model. The degree of predictability was in fact used as one of the dimensions of the model. The other important contribution was from the sources of order, control and self-organisations. Both of these are represented in the model as generic strategies. However, in the model these concepts are not treated as opposites, but as different approaches to achieving order that are suitable under different situations.

2.5.3.2 Complementary views

Complementary views are those approaches that do not necessarily form the core of Complexity thinking in strategy, but are compatible with it. These are views presented by individual authors or groups of authors, who have developed certain concepts, and, in some cases, combined them with other theories to create new models.

a) Fitness Landscapes

The concept of fitness landscapes, discussed in Submissions 1 and 2, is used to map the overall fitness of an organism to its environment using a multidimensional function. Authors such as Kelly (1998) Beinhocker (1999) and Clippinger (1999), have developed the concept and propose using it as a tool to identify and understand how evolution works and how it finds good strategies in ecology as well as in business (Beinhocker, 1999). Beinhocker (1999) suggests three vital elements for finding high peaks in fitness landscapes:

1. Keep moving: organisations should avoid equilibrium and stasis.
2. Deploy platoons of hikers: experimentation, diversity and parallelism are necessary for innovation.
3. Mix short and long jumps: manage the short and long term with different approaches.

Beinhocker (1999) argues that these three elements allow the development of a robust strategy, which is likely to cope with a diversity of future scenarios without risking the organisation's long-term future. He pictures this robust strategy as a population of strategies that cover a broad array of possibilities and evolve over time, some succeeding and some failing.

b) Types of Management

Stacey (1993) has distinguished between two distinctive types of management approaches required for dealing with the different types of change. These are Ordinary and Extraordinary management.

a. Ordinary management: this type of management is practised when most managers share the same mental models and these mental models are not questioned because managers operate in negative feedback. Ordinary management is used in relatively stable situations by applying technical rationality, and planning and ideological forms of control (Stacey, 1993).

b. Extraordinary management: this type of management, suitable for uncertain situations, involves questioning and destroying paradigms and creating new ones. This cannot be done by rational analysis or incremental change. Extraordinary management relies on intuitive, political and group-learning modes of decision-making used to change strategic direction and innovating (Stacey, 1993). In Extraordinary management, tasks are carried out through an informal organisation because the formal organisation is there to protect the status quo and not to break the paradigm (Stacey, 1993). The informal organisation is formed by small groups that self-organise, creating a learning community that can influence the political system of the organisation.

c) Time-Pacing and Experimentation

Brown and Eisenhardt have conducted extensive research into organisations operating in a high-velocity and turbulent environment (Brown & Eisenhardt, 1997, 1998; Eisenhardt & Brown, 1998, 1999). Conclusions from their research indicate that successful organisations in a turbulent environment 'create innovation by improvising through limited structures and real-time communication, experimentation into the future with a wide variety of low cost probes and rhythmically choreographed transitions from present to future' (Brown et. al., 1997). Their view is that effective decision makers create strategy through four mechanisms (Brown et. al., 1997; Eisenhardt, 2001)

a. Building collective intuition: by conducting frequent meetings and using real time metrics, allowing threats and opportunities to be seen sooner and more accurately.

b. Stimulating quick conflict: by assembling diverse teams, challenging them and stressing multiple alternatives, to improve the quality of strategic thinking.

c. Maintaining a disciplined pace: by driving the decision process to timely conclusion.

d. Diffusing political behaviour: by emphasizing common goals and clear turf, avoiding behaviour that creates conflict and wastes time.

d) Simple Rules

Eisenhardt and Sull (2001), McMaster (1996) and Tetenbaum (1998), argue in favour of the use of *simple rules* for strategy formation. They claim that simple rules can place the organisation at the Edge of Chaos, providing just enough structure to allow it to capture the best opportunities. This is suggested as the most suitable approach for 'new economy markets' where the key feature is unpredictability, not sustainability (Eisenhardt et. al., 2001).

e) Co evolution

Some authors such as Beinhocker (1997) and Eisenhardt and Galunic (2000) have explored the concept of *Co-evolution* in management. Eisenhardt and Galunic (2000) define Co-evolution in a business context as 'a strategic process used to build collaborative teams and yet rewarding self-interest and letting competition flourish'. They assert that this collaboration-competition dichotomy can allow an organisation to capture cross-business synergies better than a purely collaborative approach.

f) Information Space

Boisot (2000) has developed a conceptual framework called I-space, which represents different aspects of information in organisations. The I-space is a three-dimensional space where the axes represent the level of codification of information, the level of diffusion of information and the level of abstraction of information. Within this framework, he defines two potential strategies towards complexity: reduction and absorption. Boisot stresses that only where complexity and variety cannot be meaningfully reduced do they have to be absorbed. However, since the business environment is becoming more complex, organisations have to shift from complexity-reduction strategies to complexity absorbing ones. Boisot also stresses that there is a movement towards complexity absorption in the literature, emphasising issues such as internal competition, the need for large firms to behave like small ones and the importance of interpersonal networking.

The complementary views also had an impact on the development of the model. Stacey's ordinary & extraordinary management and Boisot's reduction and absorption strategies highlight the need for different approaches under different circumstances which is reflected in the Complexity-Uncertainty model. Similarly, suggestions presented by Beinhocker for finding peaks in fitness landscapes, and the approaches presented by Eisenhardt and Brown to operate in turbulent environments, contributed to the introduction of self-organisation as one of the generic strategies in the model.

2.5.3.3 Conflicting views

This section presents the topics within complexity and strategy where authors appear to disagree on the way the concepts of Complexity apply to strategy formation. Three main areas of conflict have been identified:

a) Vision / Mission

Most authors in the field agree that forms of control focused purely on negative feedback are not suitable for an uncertain environment and that organisations should allow self-organisation to take place in order to create new mental models (Nonaka, 1988, Stacey, 1992, 1993; Brown et. al., 1997, 1998; Eisenhardt et. al., 1998, 1999; Beinhocker, 1997, 1999).

The main area of conflict rests on the need for a vision/mission to guide the organisation through the self-organising process. Some authors maintain that although specific goals can be detrimental for the organisation, a generic vision, mission or statement of strategic intent (Hamel & Prahalad, 1994) is necessary to bring the organisation together and avoid total anarchy in the process of self-organisation (McMaster, 1996, Nonaka, 1991, Wheatley, 1994). McMaster (1996) explains that these statements of strategic intent must serve as guidelines, which should embody sufficient ambiguity to generate creativity and enough clarity to evoke common understanding.

Stacey (1993) considers visions, missions and cultures as ideological forms of control, which rely mainly on negative feedback. These approaches are therefore only suitable for situations of closed or constrained change. However in situations of open-ended change, Stacey argues, the system requires both positive and negative feedback.

In clear and stable situations leaders can exert their authority and maintain the organisation in equilibrium through negative feedback, however, if the level of uncertainty rises, the power of the leader diminishes and fear of failure develops rising anxiety levels, creating amplifying feedback loops. In these situations, only self-organising forms of control are suitable (Stacey, 1993)

b) Self-organisation

There are several different views about the precise role of self-organisation in organisations and particularly in strategy formation. Some authors such as

Battram (1998) and Coleman (1999) consider it simply as empowerment and connectivity between people. Other authors such as Stacey present a more complete view of self-organisation. Stacey (1993) presents self-organisation as a system that spontaneously emerges from the interaction of people and that it is based in learning processes and political actions (overt and covert). Nonaka and Takeuchi (1995) take a different perspective regarding it mainly as a process of creation of information.

c) Political behaviour

The role and importance of political behaviour in strategy formation is another topic about which authors have presented different views. Stacey (1993) states that political activity is fundamental in the self-organising process, as it helps to maintain the balance between negative and positive feedback. Other authors, such as Eisenhardt (2001) and McMaster (1996), consider political behaviour as a waste of time and argue that it should be diffused (Eisenhardt, 2001)

2.5.3.4 Contradictory views

This sub-section covers those views of authors that completely reject the Complexity perspective as applied to organisations and its role in strategy formation. Authors such as Hull (1997) Introna (1998), and Rosenhead (1998) directly oppose the Complexity view, disregarding its relevance in organisations.

Introna (1998) argues that despite the clear similarities between the concepts of Complexity and the behaviour of social systems, in natural systems reality exists relatively independently, while social reality is a socially constructed phenomenon. For this reason, he argues, these two domains do not share the same nature and hence they are not comparable. Introna (1998) concludes, based on this argument, that the use of the concepts of Complexity Theory in social systems would require the development of a completely new domain of understanding. Rosenhead (1998) holds a similar view, stating that organisations are social and not natural systems. Therefore, the concepts of Complexity developed in the natural sciences have been translated from one domain to the other by means of metaphor and analogy, which he considers invalid. In his critique of the application of Complexity Theory to strategy formation, Rosenhead clearly defends the position of more traditional tools to planning and strategy formation, in particular the perspectives of robustness analysis about which he has written extensively. These contradictory views were positive for realising that Complexity Theory represented only one approach, and that other views could also contribute to the development of the model.

2.6 Uncertainty

This section presents a discussion about the concept of uncertainty, based on the analysis of different definitions available in the literature. It continues with the analysis and comparison of various approaches to the measurement and classification of uncertainty. The ultimate goal of this analysis is the development of a definition and a classification of uncertainty for the Complexity-Uncertainty model. The relationship between uncertainty and complexity will be discussed as part of the model in section 4.2.

2.6.1 Defining Uncertainty

The term uncertainty is used in a variety of ways and in different contexts. In common speech, uncertainty usually refers to the lack of knowledge about an event, in terms of magnitude, duration, continuance or variation (OED, 1989).

Uncertainty is also perceived as having different degrees from just short of certainty to a complete lack of knowledge (Merriam-Webster, 2002).

Jauch and Kraft (1986) provide a classification of views of uncertainty in organisations, identifying three main groups, the classical, the transition and the process view.

a) *Classical view.* This view considers uncertainty as an objective property of the external environment, which affects factors internal to an organisation such as decisions, structure and performance. Supporters of this view, such as March and Simon (1958), Burns & Stalker (1961), Chandler (1962), and Emery & Trist (1965) emphasise that change and unpredictability in the environment require adaptation in order to reach a *state of equilibrium.*

b) *Transition view.* This view argues that the source of uncertainty is both external and internal and proposes that decision makers can choose among a number of different possible reactions to uncertainty. The focus of this view is on performance rather than on system equilibrium. Authors such as Galbraith (1973), Perrow (1970) and Terreberry (1968) represent this view. Galbraith (1973), following an information processing perspective, defined uncertainty as *"the difference between the amount of information required to perform the task and the amount of information already possessed by the organization"*.

c) *Process view*: This view emphasises the perceptions of the observer about the environment as opposed to an objective environment and highlights the difficulties in the objective measurement of the environment, to the extreme of ignoring any objective elements of the environment. A number of authors such as Lawrence & Lorsch (1967), Duncan (1972) and Downey & Solocum (1975) subscribe to this view.

Downey and Solocum (1975), emphasise the role of the observer, arguing that cognitive processes, individual response repertoires and social expectations play an important role in the perception of uncertainty. They also point out that a simple summation of individuals' perceptions of uncertainty is not a good representation of the overall level of uncertainty.

There are some definitions of uncertainty that do not fit precisely into these three categories. For example, Klippendorff (1986) defines it as "*the average number of binary decisions a decision maker has to make in order to select one out of a set of mutually exclusive alternatives, a measure of an observer's ignorance or lack of information.*" This combines the objective element of the classical view with the perceptive element of the process view. Dyckman, Smidt and McAdams (1969), have a different view, arguing that "*if a process of change can lead to more than one outcome, the outcomes are **uncertain***", and define this kind of processes as random or stochastic.

Another important dimension of uncertainty, which was not captured by the definitions presented above, is that of time. Uncertainty can range from the almost certain to the totally unexpected, however, the degree of uncertainty will tend to increase as we examine events further into the future (Rosenhead, et. al. 1989).

This research acknowledges the perception of an observer as a key element of uncertainty, leaning towards the process view (Jauch & Kraft, 1986). However, elements from other definitions have also been incorporated, such as the time dimension (Rosenhead, 1989) and the stochastic nature of processes leading to uncertainty (Dyckman, et.al, 1969). These issues will be discussed in section 4.2

2.6.2 The Measurement and Classification of Uncertainty

Probability has traditionally been used to support decisions under uncertainty, however, according to Morgan and Henrion (1990), there are many types of uncertainty where probability is not the right tool. Some types of uncertainty, like variability and random error, are good targets for probability. However, uncertainties arising from lack of information, linguistic imprecision, disagreement between experts or pure unpredictability are not good targets for probability (Morgan, et. al. 1990).

In this research, the concept of uncertainty includes many of those properties that cannot be assessed using probabilities, such as information availability, knowledge, and perception of the environment. A number of authors have proposed categorisation as an alternative approach to the measurement of uncertainty. This approach divides uncertainty in a particular situation into a series of categories representing different degrees of uncertainty.

Makridakis (et. al., 1987) suggest classifying uncertainty according to the nature of the change, identifying four main groups as shown in the following table.

Table 4: Classification of Uncertainty (Makridakis and Heu, 1987)

Category	Nature of Change	Description
Stable	Normal	Uncertainty can be assessed with enough accuracy to be incorporated into plans. Exact timing of event cannot be known. Forecasting tools can be used to identify patterns and make decisions for the future.
Progressive	Unusual	There are several possible future scenarios, and even when uncertainty can be estimated to an extent, and general patterns can be identified, details about the future, such as the timing and degree of events, are difficult to assess.
Dynamic	Unexpected	The system has a high variety of possible future scenarios. Patterns are difficult to identify, making it difficult to predict and plan.
Unpredictable	Inconceivable	At this level, the future is so diverse that inconceivable changes can take place. Forecasting, planning and strategy as they are currently perceived are not relevant
Source: Based on the classification by Makridakis, and Heau (1987)		

Courtney, Kirkland and Viguerie (1997), have developed another classification of uncertainty in relation to the knowable elements of the future and the possible approaches that companies con follow. The following table summarises this classification, including some examples provided by the original authors.

Table 5: Four levels of Uncertainty (Courtney, et. al., 1997)

	What Can Be Known?	Analytic Tools	Examples
Level 1. A Clear Enough Future	• A single forecast precise enough for determining strategy	• "Traditional strategy tool kit	• Strategy against low-cost airline entrant
Level 2. Alternative Futures	• A few discrete outcomes that define the future	• Decision analysis • Option valuation models • Game theory	• Long-distance tele-phone carriers' strategy to enter deregulated local-service markets • Capacity strategies for chemical plants
Level 3. A range of Futures	• A range of possible outcomes	• Latent-demand research • Technology forecasting • Scenario planning	• Entering emerging markets such as India • Developing or acquiring emerging technologies in consumer electronics
Level 4. True Ambiguity	• No basis to forecast the future	• Analogies and pattern recognition • Non linear dynamic models	• Entering the market for consumer multi-media applications • Entering the Russian market in 1992

Emery and Trist (1965; Emery, 1967) developed a framework of four types of environments and postulated types of behavioural responses required for survival in each category. The following table summarises Emery's classification:

Table 6: Types of Environment (Emery, 1967; Duncan 1972)

Type of Environment	Description	Behavioural requirements
1. Placid-randomised	Goals and noxiants are relatively stable and are randomly distributed	Tactics-strategy… "attempting to do one's best on a purely local basis"
2. Placid-clustered	Goals and noxiants remain stable but they tend to hand together in lawful ways. This structure enables parts of the environment to potentially serve as signs of other pats	Tactical response to each sign in the environment becomes dysfunctional. Thus, strategies become necessary in order to subordinate tactical responses to higher order goals.
3. Disturbed-reactive	The basic type-two environment remains relatively unchanged but more than one system of the same kind is present. Thus, responses by a system will be accom-panied by responses of other systems.	Strategies utilised in a type-two environment must be broadened to include competitive strategies and tactics.
4. Turbulent fields	Significant variance arises from environmental field itself in addition to that which arises from the simple interaction of like systems in the environment. Reactions precede action	Given "present" adaptive processes, time of adaptation increases beyond all bounds of what is practical.

Emery's Turbulent fields are particularly interesting for this research since they characterise a type of environment in which "*the accelerating rate and complexity of interactive effects exceed the system's capacities for prediction and hence, control of the compounding consequences of their actions*" (Terreberry, 1968)

Duncan (1972) defines two dimensions of uncertainty, the static – dynamic and the simple – complex. The static-dynamic dimension indicates the degree to which factors in a decision unit's environment remain the same over time or in a continual process of change. The simple – complex dimension refers to the number of decision factors in a decision unit's environment. Few factors represent a simple system, and many a complex one. It is important to point out that this view of the simple and the complex is different from the meaning considered for this research. However, Duncan's framework is useful in classifying in environmental uncertainty and it was decided to maintain the original terms used by the author. The following table presents the four types of environmental uncertainty obtained from the combination of the two dimensions.

Table 7: Environmental dimensions and uncertainty (Duncan, 1972)

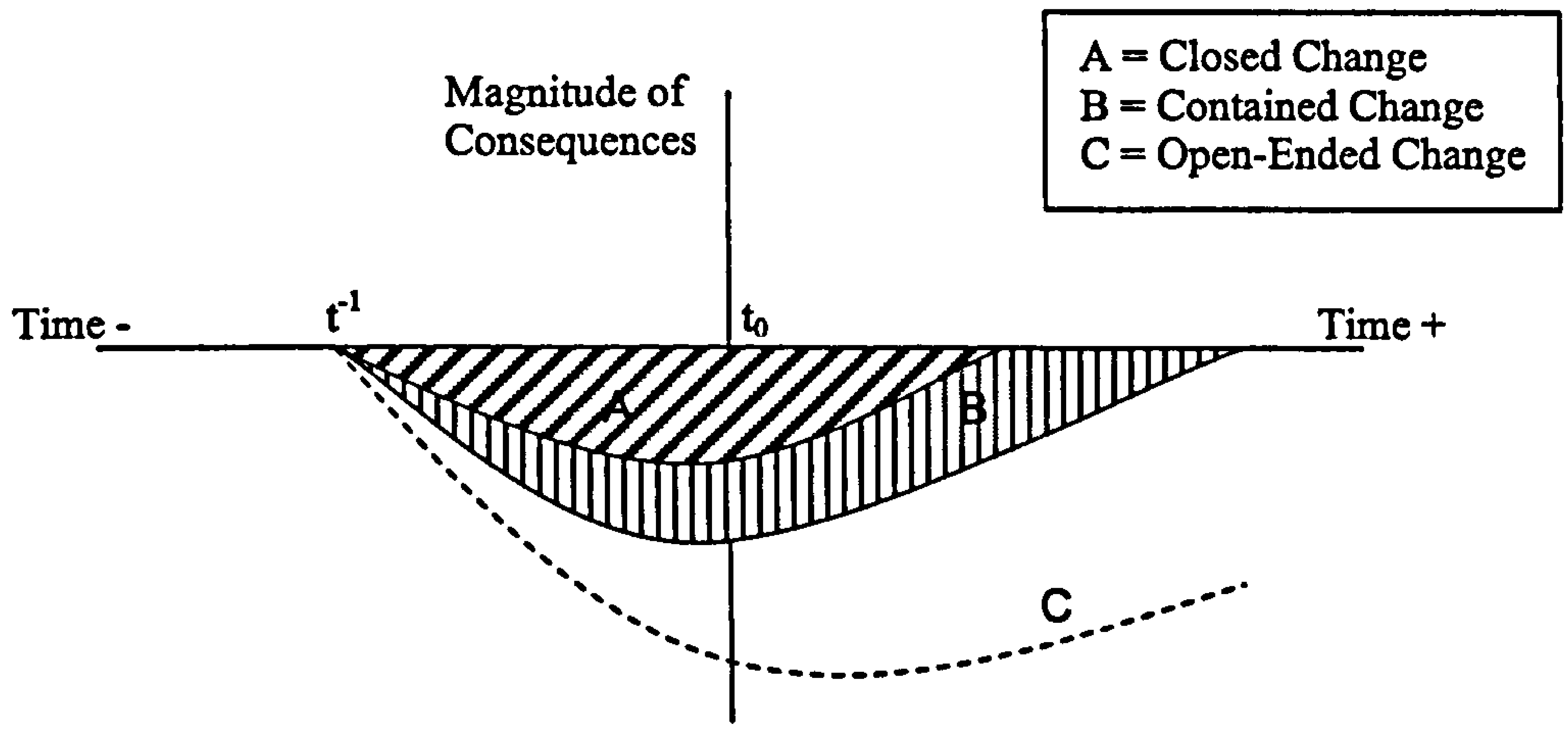
	Simple	**Complex**
Static	**Cell 1: Low perceived uncertainty** a. Small number of factors and components in the environment b. Factors and components are somewhat similar to one another c. Factors and components remain basically the same and are not changing	**Cell 2: Moderately - low perceived uncertainty** a. Large number of factors and components in the environment b. Factors and components are not similar to one another c. Factors and components remain basically the same
Dynamic	**Cell 3: Moderately - high perceived uncertainty** a. Small number of factors and components in the environment b. Factors and components are somewhat similar to one another c. Factors and components of the environment are in continual process of change.	**Cell 4: High perceived uncertainty** a. Large number of factors and components in the environment b. Factors and components are not similar to one anther c. Factors and components of environment are in a continual process of change

Stacey (1990; 1992; 1993) has developed a classification of change situations, which is also closely related to predictability and uncertainty and hence relevant at this stage. Three main categories are:

1) Closed Change: This refers to situations of equilibrium. In these situations, the consequences of events are understandable in the past and perfectly predictable in the future. In these situations, there are clear liner relations between causes and effects (Stacey, 1992; 1993)
2) Contained Change: refers to situations close to equilibrium. In these cases causality is statistical and the sequences of events can be studied using probabilities making forecasting possible. This ability to forecast diminishes over time and hence it is effective only in the short term (Stacey, 1992; 1993)
3) Open-ended Change: This kind of change refers to situations far from equilibrium where uncertainty and ambiguity are present. In these situations, it is not possible to forecast the future of the system and the connections between causes and effects are lost in the complexity of their interactions (Stacey, 1992; 1993)

Figure 9 depicts the three types of change situations in relation to time and to the magnitude of their consequences.

Figure 9: Types of Change (Source: Stacey, 1993)



According to Stacey (1992; 1993) a business must simultaneously deal with the three types of change – closed, contained and open-ended. However, the approaches used to deal with open-ended change are radically different to those used in closed or contained change. Table 8 shows the key characteristic of behaviour in the different change situations and outlines some of the models of decision-making.

Table 8: Decision-making in different change situations

Change Situation	Behaviour	Models of Decision Making
Closed / Contained	The system is close to certainty. In the short term, the development of a chaotic system will approximate that of a system near to equilibrium. Hence, in the short-term it is possible to assume a system in equilibrium.	• Technical rationality • Bounder rationality, bureaucracy and dominant coalitions • Trial and error – logical incrementalism
Open–ended	The system is far from certainty. Links between causes and effects are unclear or inexistent. The long term future is unknowable	• Search for error • Decision making process (Mintzberg) • Dialectic Enquiry • Muddling through, organised anarchy and garbage can • Politics and agenda building

The five classifications of uncertainty presented in the previous section portray different views about uncertainty, however they have important commonalities. Four of the five classifications segment uncertainty into four levels or categories. The only exception is Stacey's (1992, 1993) classification of change, which is divided into three. Table 9 compares the five classifications indicating some of the key characteristics at each level.

Table 9 show that in all of the classifications, the lowest level represents a situation of equilibrium where the future can be assessed with accuracy and it is possible to formulate plans for the future.

Table 9: Comparison of different classifications of Uncertainty

Proponents	Low ←---------- Level of Uncertainty ----------→ High			
Courtney, et. al., 1997	**A Clear Enough Future:** a single forecast can determine strategy	**Alternative Futures:** a few discrete outcomes define the future	**A range of Futures:** many possible outcomes and future states	**True Ambiguity**: no basis for future forecast
Stacey (1992, 1993)	**Closed Change**: situation of equilibrium. Future is predictable.	**Contained Change:** Situations close to equilibrium. Forecasting is possible but accuracy diminishes over time		**Open-ended Change:** Situations far from equilibrium. Impossible to forecast the future and connections between causes and effects are lost.
Makridakis and Heu (1987)	**Stable**: Uncertainty can be assessed with accuracy	**Progressive**: Several possible future scenarios	**Dynamic**: High variety of possible future scenarios	**Unpredictable**: future is so diverse that inconceivable change can take place
Duncan, 1972	**Low perceived uncertainty**: few, similar unchanging factors	**Moderately - low perceived uncertainty:** many dissimilar but unchanging factors	**Moderately - high perceived uncertainty**: few similar factor in a continual process of change	**High perceived uncertainty**: large number of dissimilar factors in a continual process of change
Emery, 1967	**Placid-randomised:** stable and randomly distributed	**Placid-clustered**: stable but structured in groups	**Disturbed-reactive:** interaction and disturbance among systems	**Turbulent fields:** interaction and emergence. No basis for prediction or control.

The categories at the highest level of uncertainty portray situations far-from equilibrium where inconceivable change can take place and where there is no basis for forecasting, planning or control. On the other hand, those categories at the lowest level of uncertainty describe situations where the future is clear and close to equilibrium. For the intermediate categories, some differences exist, however they tend to refer to situations close to equilibrium but where there is a range of possible futures, and where forecasting approaches have limited use.

2.7 Models relating complexity and uncertainty

Over the last fifty years, a number of models that relate environmental characteristics, such as change and uncertainty, to internal properties of an organisation, such as structure and strategy, have been presented. Three of these models were particularly influential in the development of the Complexity-Uncertainty model and will be briefly described here. The models are presented in chronological order.

2.7.1 Organic vs. Mechanistic Organisations

Burns and Stalker (1961) developed one of the first models relating the structure of an organisation to environmental characteristics. They defined two extreme forms of management systems, mechanistic and organic. The mechanistic form tends to be hierarchical, based on controls, rules, regulations and a specialised differentiation of functional tasks. According to Burns and Stalker (1961) this management system is more suitable for a stable environment.

The organic form is based on continual redefinition of individual tasks, a network structure of control, authority and communication and special knowledge and experience of the common tasks of the concern. This form is suggested as appropriate for changing environmental conditions. Figure 10 summarises the main characteristics of these two management systems.

Figure 10: Types of management systems (Burns & Stalker, 1961)

Mechanistic	Organic
• Specialised differentiation of functional tasks • Precise definition of rights, obligations and technical methods • Hierarchical structure of control, authority and communication. • Interaction between members is mainly vertical • Importance of loyalty and obedience • Greater importance of local than general knowledge, experience and skill	• Adjustment and continual redefinition of tasks • Shedding of responsibility as a limited field of rights, obligations and methods • Network structure of control, authority and communication • Lateral rather than vertical communication • Communication consists of information and advice rather than instructions and decisions • Importance of general knowledge and expertise
Stable Unchanging ◄—— **Environment**	——► Unstable Changing Predictable / Unpredictable

Other authors such as Perrow (1972) and Duncan (1972) have developed similar models where situations of low uncertainty require rational models of decision-making and highly uncertain situations demand more organic approaches.

These models contributed to the Complexity-Uncertainty model with the basic concept of contingency, which implies that different environmental conditions require different management approaches. However, these models did not consider complexity as an internal factor and segmented the potential strategies into two broad groups. The Complexity-Uncertainty model, however, considers a diversity of other approaches suitable under different conditions of complexity and uncertainty.

2.7.2 Coping with Uncertainty

Allaire and Fisirotu (1989) have developed a model for coping with uncertainty focused on control and prevention (or protection). They argue that there are three mechanisms for coping with uncertainty: technocratic coping, power response and structural response. These approaches are suitable under different circumstances, depending on the level of uncertainty and the capability to control uncertainty. Figure 11 presents Allaire and Fisirotu's model, followed by a brief description of each of the coping mechanisms.

Figure 11: Control & Coping Mechanisms (Allaire and Fisirotu, 1989)

Level of Uncertainty (volatility and unpredictability)

Degree of potential control on source of Uncertainty	Low	High
High	**Technocratic Response** (predict and prepare)	**Structural Response** (built-in insulation and flexibility)
Low	**Technocratic / Power Response**	**Power Response** (act to create / control the environment)

- **Technocratic coping:** "*Predict and prepare*" This approach is based on an attempt to deal with the future using analytical tools such as forecasting, simulation, judgemental prediction and corporate planning models (Allaire et al., 1989). The limitations of this approach are acknowledged by placing it in the low uncertainty, low control quadrant.

- **The Power Response:** "*Don't predict the future, Control it!*" This approach attempts to exert control over events in the environment using power. This can be done by simply shaping or controlling the environment, passing risk on to others, disciplining competitors or using the courts.

- **The Structural Response:** "*Be ready for whatever It is*": This mechanism, suitable for situations of high uncertainty but where the potential of control is low, is based on making the organisation more responsive, flexible and adaptable to uncontrollable events (Allaire et al., 1989). This can be achieved by maintaining a broad and diverse base, by broadening the product and market scope, by using decentralised control and by absorbing uncertainties over which no control can be applied.

Allaire and Fisirotu's model does not explicitly talk about internal complexity. However, it does emphasise that a diverse base of resources and a broad product and market scope, all elements of increasing complexity, would allow the organisation to be more flexible and responsive in situations of high uncertainty and low potential of control. It also possible to see some strategies that are congruent with complexity theory such as the use of decentralised forms of control.

It is important to note that the three approaches for dealing with uncertainty in Allaire and Fisirotu's (1989) model are closely related to the some of the strategies in the Complexity-Uncertainty model. The technocratic coping approach is similar to the planning strategy, the power approach resembles the control strategy and the structural response has some similarities with the self-organising strategy.

2.7.3 Order from the bottom-up

Clippinger (1999) has developed a model, which, according to the author "*identifies a range of options confronting management in achieving fitness*". This model has two dimensions, internal complexity, defined as interconnectedness of the organisation itself, and external ruggedness, defined as interconnectedness of environmental factors (Clippinger, 1999). The model segments organisations into four types, two of which are viable, the Classical Stereotype and the Catalytic Network, and two which are not, the Byzantine Monolith and the Endangered Denier. Figure 12 presents a depiction of Clippinger's model.

Figure 12: Mapping the fitness landscape (Clippinger, 1999)

Internal Complexity	External Ruggedness: Low	External Ruggedness: High
High	**I. Byzantine Monoliths**	**IV. Catalytic Networks (Viable)**
Low	**II. Classical Stereotypes (Viable)**	**III. Endangered Deniers**

a. **Byzantine Monoliths:** are defined as organisations that are over-organised relative to challenges in the environment. This type of organisation is considered non viable because it cannot cope with uncertainty in the environment (Clippinger, 1999). Some examples are bureaucracies, monopolies and unresponsive companies.

b. **Classical stereotypes:** these are simple and well adapted organisations in a stable environment. These organisations are viable because they are adapted to their stable environment. Examples in this category are legal, political and religious institutions that face little change (Clippinger, 1999).

c. **Endangered deniers:** these are organisation where the environment is significantly more complex that they can handle. According to Clippinger, for organisations in this category extinction is virtually certain.

d. **Catalytic Networks:** the complexity of the organisation matches the challenges of the environment. In these networks, emergent organization is the source of continuous innovation.

This model, as the author (1999) himself admits, is a vast oversimplification, however it is useful for communicating some key concepts. In fact, this is the only one of the models presented that explicitly refers to the concepts of Complexity Theory, such as self-organisation, emergence and fitness landscapes.

The main influence of Clippinger's ideas on the Complexity-Uncertainty model was on the dimensions of internal complexity and external ruggedness. However, two important limitations identified in this model were also influential. Firstly, Clippinger's model encapsulates an entire organisation in one of the four categories, without acknowledging that parts of the organisation can face different challenges in the environment and may require different approaches. However, certain areas within the organisation could be viable while others could not. The second limitation is that it considers that organisations are either completely fit or totally unfit. However, neither of these two extremes seems possible. For example, if the Byzantine Monoliths and the Endangered Deniers were not viable there would be no organisations populating these two categories.

The three models presented here were informative for the development of the Complexity- Uncertainty model. They not only contributed important concepts, but also revealed limitations, which could be surmounted by a new model.

3 Methodology

3.1 Research Problem and Objectives

One of the main motivations for doing this research was to understand how people in organisations deal with complex and uncertain situations and to help them in their decisions. A literature review revealed many different views of organisational complexity, ranging from a harmful and avoidable property to an essential element for the evolution and sustainability of organisations, which cannot be controlled. The literature indicates that many managers have tended to support the first of these views attempting to simplify it and control it. However, Complexity Theory has started to present an alternative view.

This research intends to explore how managers make decisions about complexity and how they use the different views. Based on these arguments, it is possible to state the following two research questions:

How do managers deal with situations of complexity and uncertainty?

How can organisations benefit from incorporating the concepts of Complexity Theory into their thinking?

To answer these questions a conceptual model of the strategic alternatives to deal with complexity and uncertainty has been created. Hence, the research questions can be rephrased in the form of a general objective as follows:

To create a model for dealing with complexity in organisations by exploring the use of the concepts of Complexity Theory and the approaches used by people in organisations to deal with situations where complexity is a dominant feature.

This general objective has been broken down intro three specific objectives:

1. To identify in the literature the concepts and applications of Complexity Theory that are relevant to organisations

2. To analyse the strategies used by four selected companies to manage complexity, and to assess how the concepts of Complexity Theory can be incorporated.
3. To create a model of generic strategies, which can help decision makers to understand and deal with complexity in their organisations.

The challenge of the research is to create a model that takes into account the different views of complexity. This is intended to help managers facing complex situations, enabling them to understand the nature of complexity and providing them with general guidelines on how to deal with it.

3.2 Research Paradigm and Methodology

This research is exploratory, and is aimed at understanding how managers in industry make decisions about complexity and uncertainty and at creating a conceptual model. This requires an inductive process in building the model.

An important part of this research is to gain an in depth understanding of how managers deal with different situations. Usually situations in industry are difficult to isolate and are continuously being influenced by changes in the organisation and the environment. An effective approach to gain this detailed understanding is to have direct access to the people, processes and activities taking place in an organisation. This approach involves understanding people and their perceptions in a social context by the direct access of the researcher to the subject of the research. This inclines more towards a qualitative or phenomenological approach to research which focuses on understanding meaning rather than measurement (Hussey et. al., 1997).

Having defined an overall paradigm, it is necessary to move on to defining the research strategy. Yin (1994) proposes three conditions for defining the research strategy:

(a) the type of research question posed

(b) the extent of control an investigator has over actual behavioural events, and

(c) the degree of focus on contemporary as opposed to historical events

The two research questions are **how** type questions. The approach to answering these questions is by gaining access to companies to understand how people within these organisations make decisions. This means that the investigator has limited control over the events being studied. The fact that the problem under research is current implies that the events under study are contemporary. Having answered the three conditions proposed by Yin (1994), it is possible to use Table 10 to support the selection of the research strategy.

Table 10: Conditions for defining the research strategy

Strategy	Form of research question	Requires control over behavioural events?	Focuses on contemporary events
Experiment	how, why	Yes	Yes
Survey	Who, what, where, how many, how much	No	Yes
Archival analysis		No	Yes / No
History	how, why	No	No
Case study	**how, why**	**No**	**Yes**
Source: Yin (1994:6)			

Yin's table helped to rule out two of the strategies, experiment and history, and left the other three strategies available: survey, archival analysis and case study. A survey is a positivistic methodology, which looks for statistical significance of the results and where the researcher is generally detached from the subject of study. These characteristics are not consistent with the phenomenological approach selected for this research, nor with the intention of becoming directly involved with the research subjects. Furthermore, the concepts of complexity, such as self-organisation, emergence and chaos, are not part of the common language and usually require a detailed explanation, which would be difficult to achieve in a survey. For these reasons surveys were not considered as a suitable strategy for this research.

Archival analysis requires the existence of archives relevant to the research subject. This research focuses on managers and how they make decisions under certain circumstances, and requires extensive information about the decisions an their specific context. Finding this kind of information in archives would be unlikely, which makes this approach unsuitable for this research.

A case study is a phenomenological methodology, which involves an extensive examination of an instance of a phenomenon of interest (Eisenhardt, 1989). Case study research focuses not only on exploring a phenomenon, but also understanding it within its contexts (Yin 1994). This research strategy, according to Blaxter, Hughes and Tight (2001) is suited to the needs and resources of the small-scale researcher, who can focus on just a few examples. Each of these few examples requires a large amount of work to get the depth required, which explains why the number of possible case studies is often restricted. Furthermore, according to Eisenhardt (1989) the final product of a case study may be a conceptual framework, which is precisely the aim of this project. For these reasons case study research was considered the most appropriate strategy.

In this project, the researcher aims at achieving innovation by creating a new model and demonstrating industrial relevance by helping the collaborating organisations to deal with complex situations. A methodological approach that shares this dual purpose is *action research*. This approach pursues action (change) and research outcomes at the same time (Dick, 1999). The action component and the research component are both in the nature of the project, making action research approaches appropriate.

In conducting cases in commercial organisations, the researcher's responsiveness is an essential element. In this kind of project, a researcher needs to adapt to situations and to take appropriate courses of action in order to produce change in the organisation. One benefit of an action research approach is that it allows a high degree of responsiveness to situations involving change. This responsiveness comes at a price, mainly the sacrifice of replication. This was a difficult trade-off, because both responsiveness and replication are important elements in this research project. To provide replication, five case studies were conducted with four collaborating companies.

3.3 Case Studies Selection

The selection of the case studies was done in collaboration with the project sponsors in the collaborating companies. The main criterion was to find a complex problem. To make the decision it was necessary to discuss with the sponsor the requirements of the research and to make clear that complexity referred not only to a complicated interrelation of parts, but also to a rich set of possibilities and patterns in the behaviour and evolution of the organisation. The result was a set of cases where complexity was the common thread.

According to Eisenhardt (1989), "there is no ideal number of cases but a number between 4 and 10 usually works well". For this research five in-depth case studies were used to develop the model. The first three contributed to the development of the model and the final two to the validation.

Four of the case studies were with companies in the aerospace/aviation industry, providing a measure of consistency in scope. By the end of the research there was an opportunity to conduct a final case study in the automotive industry. It was decided to conduct this case because it had the potential of enriching the findings obtained from the previous case studies.

To understand the complexity and uncertainty of the situations, it was necessary to develop openness with the people involved in the operation and to know the context in which they were making decisions. In order to develop this openness it was decided to get involved in a specific project in the companies. This also facilitated the triangulation of sources of information, since the researcher had the opportunity to interact with a number of people in the operation

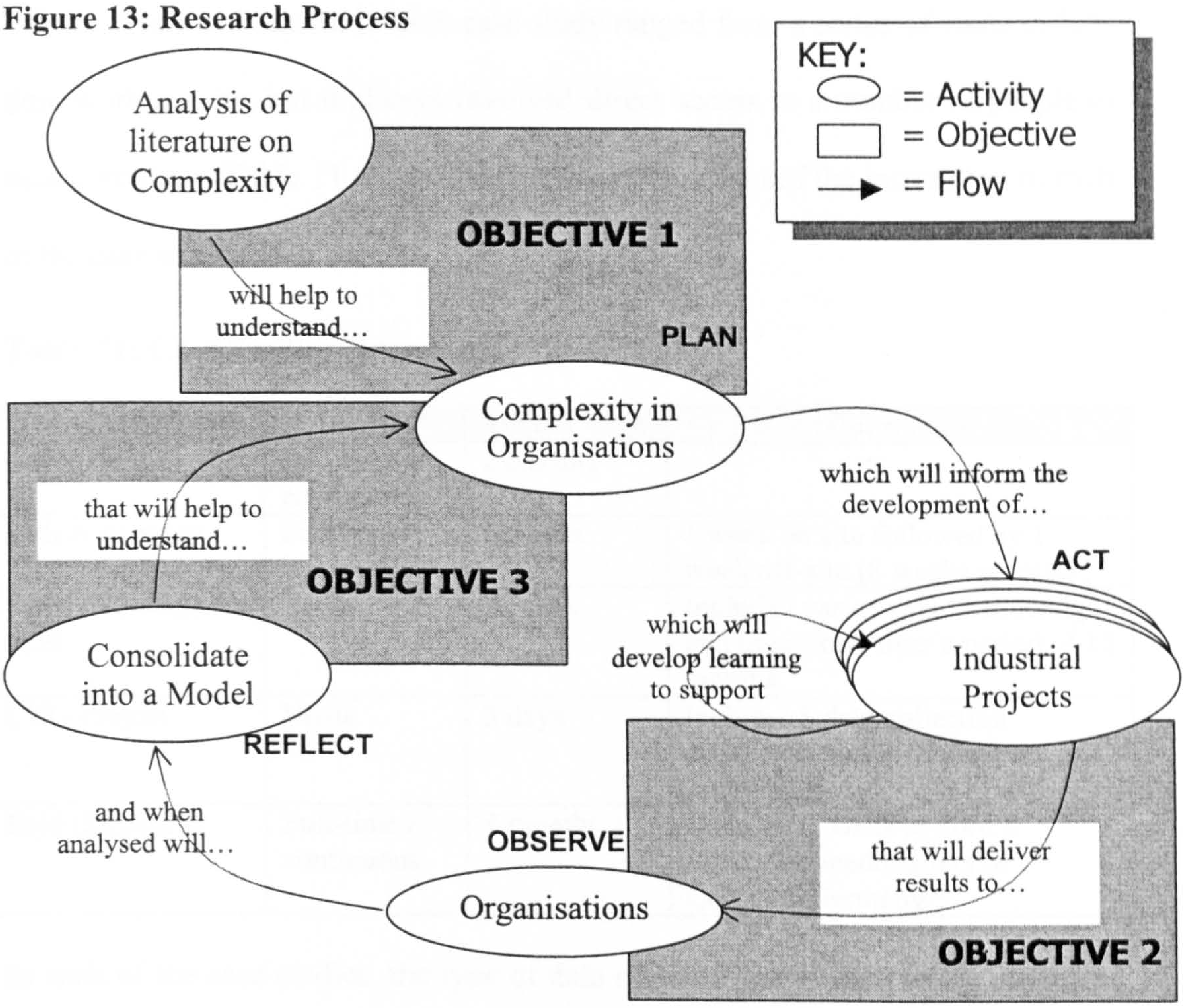
In order to understand and explain the operation of the companies and their relationships with the environment, models of the real system were constructed. To build these models, the systems approach to action research was applied to each of the case studies (Arbnor & Bjerke, 1997). This approach suggests that reality is constructed of units (systems) that are intimately related, and accepts that our interpretation of reality has both objective and subjective aspects (Arbnor et. al., 1997).

3.4 The Research Process

The research followed a cyclical process typical of action research (Dick 1999, 2000). In this process, the information obtained from the case studies was used to reflect on and draw conclusions about complexity in the organisations involved, and to support the creation of the model. The case studies were not conducted simultaneously, and the process of creating the model took place gradually through the cyclical process of reflecting and learning. Hence, it is possible to say that the model emerged from the cyclic process.

Figure 13 shows the main activities of the research, the logical flows between stages and the contributions to the objectives at each stage. The process follows the four stage cyclical structure of planning -> acting -> observing -> reflecting (and then plan again) as suggested by Kemmis and McTaggart (1990).

Figure 13: Research Process



The research process diagram also shows the process of evolution of the model. This process starts by investigating complexity theory, its origins, evolution, concepts and potential applications to organisations. This initial understanding of complexity in organisations was achieved by means of a literature review. Then, the case studies helped to develop this understanding by looking at how managers dealt with complex problems and how the change process took place. During the cyclical process, the model was continuously compared with the actual data supporting the process of development. Finally, the collection of case studies was consolidated into a model that could be used to support further decision-making in terms of the strategies required for managing complexity.

3.5 Data Collection Methods

The level of involvement in each case study ranged from a series of visits to full-time work on site, but it always involved direct access to a number of people in each company. Table 11 shows the format and duration of the interaction in each of the case studies.

Table 11: Case Studies Interaction

Case Study	Format	On-site Time	Comments
British Midland	Full-time / continuous	2 months	
British Airways TRT	Full-time / intermittent	4 weeks	1 week on site followed by 1 week off-site (8 weeks in total)
British Airways TDR	Visits	10 days	Included various visits, meetings and interviews over a period of 18 months.
CXD Project	Visits	3 days	Includes 5 data collection interviews and 2 validation interviews
Ford (DEALIS)	Full-time / continuous	4 months	Included 3 visits to Ford's European headquarters in Cologne, Germany

In each of the case studies, the type of data required was related to the processes and activities of the problem under study, the environment and the strategies applied. As recommended by Eisenhardt (1989) and Yin (1994) multiple methods of data collection were used, and these included both qualitative and quantitative data. Three main methods were used, interviews, observations and documentation. Details of each of these methods are explained as follows.

a) Interviews

Interviews were the main method of data collection in this research. This was considered an appropriate method to understanding the uncertainty and complexity of situations that managers face in industry. Easterby-Smith (et. al., 1991) provide some suggestions regarding the situations where semi-structured and unstructured interviews are appropriate. Table 12 presents these five suggestions in relation to this research.

Table 12: Suggestions for the use of Interviews

Suggestion	Relevance to this research
1. It is necessary to understand the construct that the interviewee uses as a basis for his or her opinions	The objective of the interviews was to understand not only the actions that the interviewees took in making decisions, but also their reasons.
2. One aim of the interview is to develop an understanding of the respondent's world so that the researcher might influence it either independently or collaboratively	The research relates internal complexity to external uncertainty; hence, it is essential to have an understanding of the respondent's world. The action research approach used for this project relates to this point.
3. The step-by-step logical situation is not clear	Understanding processes and their logic was an important part of the case studies.
4. The subject matter is highly confidential or commercially sensitive	This issue was relevant for the British Airways TDR project where confidentiality was important and a confidentiality agreement was required (see submission 7 page 3)
5. The interviewee may be reluctant to be truthful about this issue other than confidentially in a one-to-one situation.	In the resolution of problems in the companies, face-to-face interviews gave an opportunity for people to be truthful about the situation and how to deal with it.

All of these suggestions are relevant to this research, supporting the decision of making interviews the main form of data collection.

The decisions regarding the number and identity of the interviewees were made in collaboration with the main contact within the company, which was usually the manager of the area under study. With their assistance it was possible to identify the key fact holders who could contribute to the research, this depended mainly on their functional responsibilities and previous experience. Some cases, such as the ones with Ford and British Midland, required several interviews to gain understanding of the process. Other projects, such as the BA-TDR and the CXD project, which were based on simulations required fewer interviews. Figure 14 shows a breakdown of the interviews conducted in each case study.

Figure 14: Interviews per Case Study

Case Study	Total	Breakdown
British Midland	12	2 Divisional Directors (OE) 6 managers in commercial division 4 internal customers
British Airways TRT	6	2 MPC manager 4 internal customers + day-to-day conversations with operators
British Airways TDR	7	1 (project manager) 6 various managers 1 people in operations)
CXD Project	7	3 design / 1 purchasing 1 manufacturing / 2 sales
Ford (DEALIS)	9	2 Project manager (OE) 3 Traffic managers / 1 Logistics 1 Systems Planning/ 2 Project coordinator UK
Note: Interviews marked as OE were open ended the rest were semi-structured.		

The interviews were semi-structured, allowing flexibility to adapt to emerging issues. In some cases open interviews were also used, particularly when the objective of the interview was to gain understanding about general issues rather than to collect specific data about the operation. The interviews were aimed at collecting information related to the complexity of the operation and the uncertainty in the environment.

Interview guides including the questions and topics for discussion were prepared and sent to the interviewee in advance. The structure of the interviews was adapted from Harrington (1991) and consisted of four main sections, an introduction, a set of informational related questions, a set of subject related questions and a closing section. The informational and subject related questions depended on the operation of the company and the expertise of the interviewee. In general, four subjects were discussed, the responsibilities of the interviewees, his/her perception of complexity and uncertainty and the strategies used to deal with both complexity and uncertainty. Appendix 1 presents two examples of questionnaires used with British Midlands for the Measures of Performance project and with HS Marston for the CXD project respectively.

The main way of recording the interviews was through notes taken during and after the interview. A summary of the interview was prepared to clarify the main points. Appendix 2 shows a sample of interview notes. In the case of the CXD Project, the interviews were taped and full transcripts were produced. The reason for this was that various interviewers were involved in the project. Here it was possible to access all of the transcripts and use them to support the research.

The interaction with people in the companies gave rise to opportunistic data collection situations, which came in the form of informal conversations face-to-face, over the telephone or by e-mail, as well as unplanned observations. Those considered relevant for understanding complexity and uncertainty were transformed into more formalised approaches of data collection.

b) Observations

The access to the companies allowed many opportunities for observation, which were used as an additional source of evidence. Some observations were planned and had structure, such as site visits, meetings and internal presentations. Some others were more informal and came about as a result of being based on site.

Notes and diagrams based on the observations were produced and later used at the data analysis stage. An example of these notes is presented in Appendix 3, including observations from a series of meetings conducted with personnel from British Airways on the TDR project.

Observations were used as a support method to allow triangulation. This approach was considered as a main data collection method because of its limitations regarding subjectivity and observation bias (Hussey, et. al., 1997).

c) Documentation

The analysis of documentation was also used as a support method for data collection, using both internal company documents and external documents. At the beginning of each project a general search for information relevant to the company and the industry was conducted. In the cases of British Airways and Ford it was possible to have access to annual reports. For British Midlands and HS Marston (CXD Project) financial reports were obtained using an on-line database of British companies (AMADEUS, 2001). In some cases, it was possible to obtain marketing reports, or other publications that referred to the companies involved. Figure 15 shows the main documents used in each of the case studies.

Figure 15: Key documents per Case Study

Case Study	Key Documents
British Midland	• British Midland Annual Report 1997 • Commercial Department Performance Measurement (BME-Commercial Department: 12/1997) • Basic Business Processes: LOG 274 (BME; 28/11/1997) • Project SOAR Proposal (WMG – circa 03/1998) • Project SOAR – Terms of Reference (BME; 11/10/1999) • World Airlines and Suppliers Guide (Air Transport Association of America: 01/1994)
British Airways TRT	• British Airways Annual Report 1997 /1998 • Turntime Compression Project – Update (Wicker, 24/3/98) • Component Overhaul Control & Certificate Sheet (for various components) • Work with Planning Policies (MPC – 26/22/98) • Supply Chain: Weekly Operational Performance Report (Mintram; 12/11/98) • Breakdown of part number arising according to origin (MPC – 14/10/98) • Pneumatics & Hydraulics: Weekly results (various reports) Produced: Pneumatics & Hydraulics, Nov / Dec 1998
British Airways TDR	• British Airways Annual Report 1999 • British Airways Financial Summary Report • Airlines 2000 Market Report, (KeyNote: Fen, 2000) • BA Fleet 2 Schedule - Summer 2000 (BA: October 2000) • Summer 2000 Substitutions file (BA: October 2000) • Summer 2000 Cancellations file (BA: October 2000) • Flee2 Details File (BA: November 2000) • Operations Robustness Model: User Manual (BA: 11/4/99)

Case Study	Key Documents
CXD Project	• EPSRC-IMI Research Proposal: The Complexity of Product Definition (Grant # GR/M23649 and GR/M24226) 08/98
Ford (DEALIS)	• Ford Annual Report 2000 • DEALIS Project Report Summary (CSC: 25/8/2000) • DEALIS (Distribution Export and Logistics Information System) Project Presentation (Mueller; 08/06/1999) • Network Integrator Strategy for FCSD Europe: AS IS/TO BE (F CSD; Circa 01/2000) • External Factors-Emerging Issues (Corporate Economics and Strategic Issues; 17/03/2000) • Competitive Strategies and Trends – External Factors Review (Ford – 04/04/2000)

The documents in Figure 15 helped to provide contextual information about the industry, the companies involved and the specific problems under study. In some cases they supplied specific data required for the project, for example, in the case of the British Airways TDR project, data concerning substitutions and cancellations of flights was required for the simulation. More specific details about the use of the documents are presented in the submissions corresponding to each of the case studies.

3.6 Data Analysis Methods

The methods of analysis used for the research are classified into those used to analyse the information within the individual cases (within case methods) and those used to compare and contrast across case studies (cross-case methods). The methods used for each class are described in the following two sub-sections.

a) Within Case study methods

The within-case analysis involved writing-up detailed reports of the case studies and presenting descriptions of events with each of the cases. These reports are presented in submissions 4 through to 8. According to Eisenhardt (1989) these reports are 'central to the generation of insight because they help researchers to cope early in the analysis process with the often enormous volume of data'. The reports then served as an input to the cross-case analysis.

Since each of the case studies was aimed at solving specific problems, the analysis tools required were different from case to case. Two tools that were used consistently throughout the case studies were mind maps and matrices, because these are generic tools that can help to structure data. These tools helped to make sense of the situations and to structure ideas in a consistent way in terms of analysing the complexity and uncertainty in each case. Examples of the use of mind maps and matrices are shown in Appendix 4. Table 13 presents a list of the analysis tools used in each of the case studies and the purpose of using them. The general purpose of these tools was to structure and analyse the data, and to gain a better understanding of the operation and the factors affecting it. More details about the use of the tools are presented on the corresponding submissions.

Table 13: Tools for within-case analysis

Case Study	Main Analysis Tools	Purpose
British Midland	• Matrices • Mind maps	• Structure / analyse data • Structure / analyse data
British Airways TRT	• Matrices • Mind maps • Descriptive Statistics • Time-based Process Maps	• Structure / analyse data • Structure / analyse data • Analyse process • Analyse process
British Airways TDR	• Matrices • Mind maps • Descriptive Statistics • Regression Analysis • Flow diagrams • Simulation (Discrete Event) • ANOVA	• Structure / analyse data • Structure / analyse data • Analyse fleet performance • Analyse fleet performance • Analyse process • Analyse process • Analyse simulation results
CXD Project	• Matrices • Mind maps • Simulation (Genetic Algorithm) • Design of Experiments	• Structure / analyse data • Structure / analyse data • Analyse design process • Analyse simulation results
Ford (DEALIS)	• Matrices • Mind Maps • Flow diagrams • Entity-Relationship Diagrams	• Structure / analyse data • Structure / analyse data • Analyse process • Analyse processes

b) Cross Case-study methods

Cross-case analysis was used to search for patterns among the case studies, which would help to obtain a deeper understanding of the issues involved and to improve the reliability of the study. This analysis helped to identify and explain the conditions under which each of the generic strategies were being used, to understand how the strategies were related, and in general, to synthesise the use of the strategies by the collaborating companies in different situations.

The sequential structure of the project allowed the emergence of patterns to be seen as the research took place. The within-case analysis and particularly the use of mind maps helped to classify the approaches that the organisations were using into categories, which culminated with the definition of the five strategies.

The main approach to cross-case analysis was the use of meta-matrices as recommended by Miles and Huberman (1994). The information generated from the analysis of the individual cases studies was used to compare the differences and similarities of the categories that emerged from each case study. This was an iterative process, since the findings emerging from each case study were incorporated into the analysis. After the iterative process, it was necessary to compare all the case studies with the emergent framework.

The model, with its complexity and uncertainty dimensions, provided a matrix where the individual case studies were compared. This helped to compare the strategies used in each case and to show that the model fitted the data.

Having constructed the model, the definitions of the strategies and dimensions were refined using the available literature. This process also helped to analyse any possible conflicts with other available theories. The results of this process are presented in Submission 9 and further developed in this document.

3.7 Validity and Reliability

Three validity and reliability tests for exploratory case study research are suggested by Yin (1994): construct validity, external validity and reliability. The steps taken to perform these tests are explained as follows.

a) **Construct validity:** to minimise the effects of a subjective interpretation, multiple case studies were conducted and multiple sources of evidence were used whenever it was possible. Semi-structured interviews were the most common form of data collection, and supporting methods such as observations, documents and simulations were used for triangulation.

   The active participation in the companies was an important element of the validity of the research. This helped to develop open relationships with the people in the companies and gave the opportunity to observe the people and the operations extensively.

   A draft report of each case study was produced and given to the company for review before producing the final report. In all of the cases there was a final presentation, where people from different departments, senior managers, and senior researchers from the University were present. This allowed discussion about the validity of the results and conclusion.

b) **External validity:** Yin (1994) suggests *replication* as the main tactic for dealing with external validity. This tactic was supported by the five case studies. It would be unrealistic to expect exact replications in this kind of research, as all organisations and departments within them are unique and responsiveness to changing situations was important.

   It was possible to maintain a certain degree of homogeneity in the selection of the cases by choosing medium to large organisations, involved in engineering and logistics activities and which have a profit making purpose. Four of the case studies were conducted in the engineering divisions of companies in the aviation/aerospace industry (British Midland, British Airways and HS Marston). The case study with Ford allowed the establishment of commonalties with the cases in the aerospace/aviation sector, thus helping to expand the domain in which the findings of the research can be generalised. The commonalties between the companies allowed a certain degree of generalisation across the companies. However, more replications would be required to generalise the findings to the entire industry or to other industries.

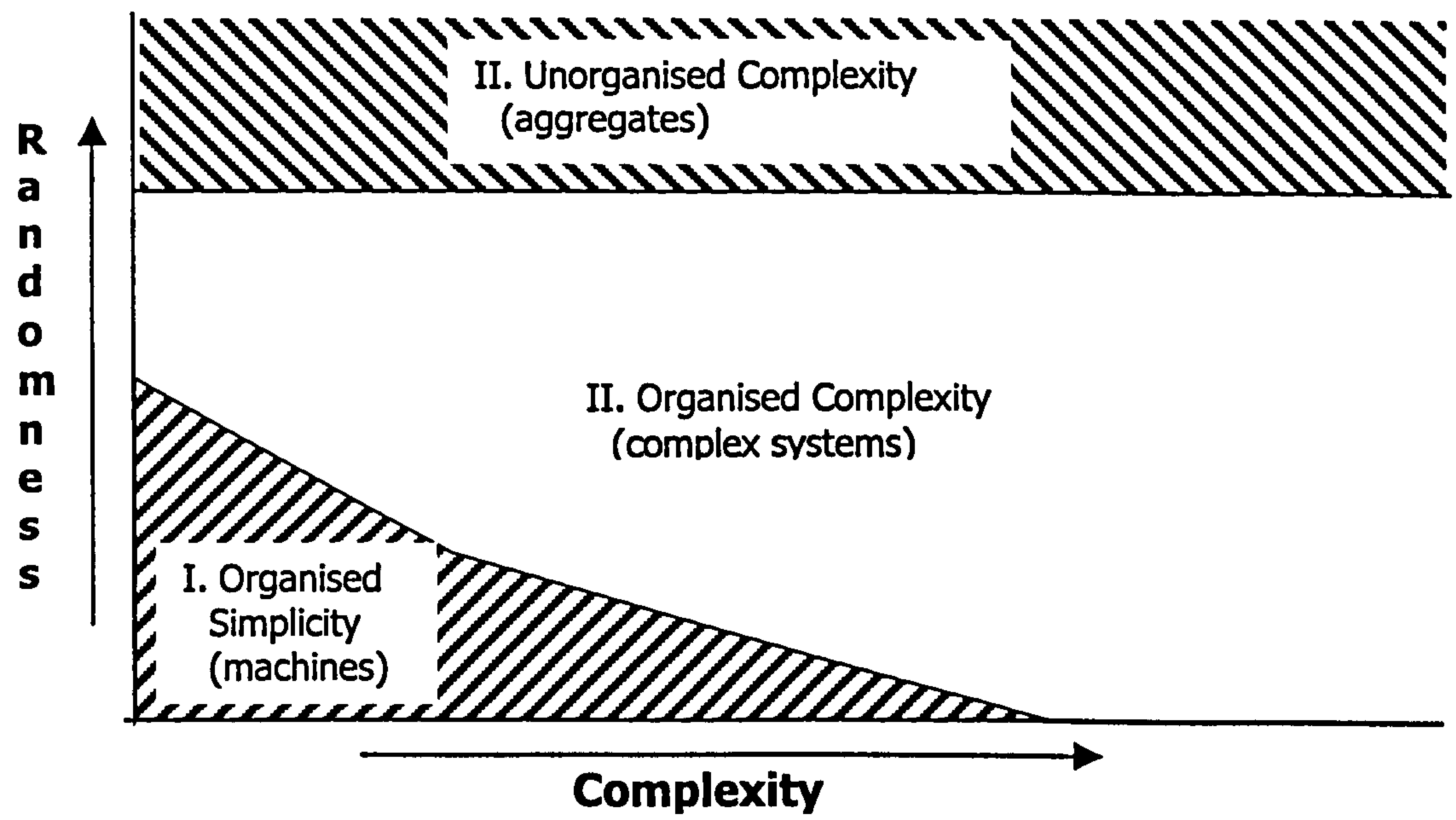
c) **Reliability:** The application of a systems approach to the case studies provided a common structure that can be reproduced in future studies. In each of the projects different business processes were analysed and the diagrams are included in the submissions, allowing other researchers to verify the findings. In the projects that involved simulation, the data collected and the algorithms are included in the submissions, making it possible to replicate the experiments.

4 The Complexity – Uncertainty Model

4.1 The Origins of the Model

The development of the Complexity – Uncertainty Model originated from the literature on complexity, systems theory and cybernetics, and evolved through the experience provided by the case studies. In the early stages of the research a framework developed by Weinberg (1975) was particularly influential. This framework, introduced in Submission 1, has two dimensions, complexity and randomness, as shown in Figure 16.

Figure 16: Weinberg's Framework



Weinberg (1975) defined three different regions:

I. *Organised simplicity:* this area of low randomness and low complexity is also termed the region of machines and mechanisms. Systems in this category can be analysed in detail by breaking them down into their components and studying their relationships. A purely analytical approach is suitable for systems in this region.

II. *Unorganised complexity:* the area of high randomness or the region of populations and aggregates. This is the area for those systems that are complex but sufficiently regular to be studied using a statistical approach.

III. *Organised complexity:* This region groups all the phenomena that are too complex for analysis, and cannot be aggregated for the use of statistics. This region comprises the most complex problems, where analytical and statistical tools are not suitable. According to Weinberg (1975) in this region "*... we can expect that large fluctuations, and discrepancy with any theory will occur more or less regularly*". Synthetic and even conflicting approaches are required to understand systems in this region.

This framework was considered useful because it relates complexity and randomness, a term that is closely related to uncertainty and because it provides a categorisation of regions, each one requiring a different approach. However, Weinberg did not provide definitions for complexity and randomness, and therefore it was necessary to develop definitions for this research. These definitions are presented in the following section.

4.2 Dimensions of the model

4.2.1 Complexity

The concept of Complexity has been discussed in previous submissions, particularly Submissions 1 and 2, as well as in the literature review section of this document. These discussions show that the concept is used in various different contexts and can be defined in different ways. The diversity of definitions expressed in the literature, made it necessary to identify one for use in this research. This definition which follows, was developed based on the definitions discussed in section 2.1, incorporating elements such as number of parts, the interconnectedness of the system and variety of states:

> **"Organisational Complexity refers to the perceived variety of entities, relationships, rules and behaviour that an organisation can exhibit"**

For this research, complexity is considered as an *internal* property of the system under study. This does not mean that complexity is not present outside this system. Every system contains complexity; the issue is one of defining the unit of analysis.

As discussed in the literature Review, Complexity is context-dependant and for this reason the perceptual component was introduced. The perception in this case refers to the point of view of the researcher, however, this is based on the understanding of the context and the interaction and discussion with members of the organisation.

Ashby (1956) has suggested variety as a measure of systemic complexity, referring to the number of distinguishable elements in a system, or the number of distinguishable systemic states. To use variety as a measure of complexity would be consistent with the definition provided, but to account for all the possible distinguishable elements and states of an organisation appears to be an insurmountable problem. As discussed in Section 2.2, similar issues appear in the use of other approaches to measuring complexity, and so it is suggested that a classification of the degrees of complexity can be a suitable alternative. A number of classifications of complexity were also discussed in Section 2.2 and Table 2 (pp. 18) presented a summary of these classifications. Based on this comparison it was possible to develop a classification for this research. Table 14 presents this classification outlining the characteristics of systems at three levels of complexity: simple, complex and exceedingly complex. The terminology used to refer to the different categories differs between authors and in this case it was decided to follow Beer's (1967) terminology, although the definitions used have been informed by a number of other authors.

Table 14: Complexity of Systems

Categories	Characteristics
Simple	• Few components • Few interrelations between components • Predictable behaviour (high degree of certainty of outcomes)
Complex	• Collection of simple systems • Interconnected but with limited interdependence • Degree of predictability diminishes
Exceedingly Complex	• Collection of simple and complex systems • Highly interrelated and interdependent elements • Cannot be described in precise and detailed form (Irreducible) • Outcomes are uncertain

This classification was then used to analyse the situations in each of the case studies. It is acknowledged that this classification does not provide an exact method for assessing the complexity of systems, however, it is helpful in providing a standard for comparing different systems.

4.2.2 Randomness and Uncertainty

According to Dyckman (et. al. 1969) a random process is one where outcomes are uncertain, this means that it can lead to more than one outcome. This implies that the degree of randomness is related to the degree of uncertainty in the system. The term uncertainty, however, is more commonly used and understood in organisations and for this reason it was preferred for this research.

The concept of *uncertainty* presents similar difficulties to that of complexity, in the sense that it has been used in different contexts and with different connotations. A number of definitions and views were discussed in Section 2.6.1. The view adopted for this research is the process view, which emphasises the perceptions of an observer of the environment as opposed to an objective environment. Uncertainty then, refers to the perceptions about variety and change in the environment. These perceptions are shaped partly by the current knowledge of the environment: the less the knowledge available about possible states, the greater the uncertainty. Based on these arguments, it is possible to formulate the following definition for use in this research:

"Uncertainty refers to the perceived variety of states in the environment, the perceived degree of change and the amount of knowledge about these states for a particular system"

Based on this definition and on the analysis of a number of classifications of uncertainty, discussed in section 2.6.2, it was possible to develop a classification system for this research. The terminology of the categories is consistent with that of Makridakis and Heau (1987), however some minor adaptations have been made, based on the work of other authors, as discussed in the literature review. The following table summarises each of the categories.

Table 15: Classification of Uncertainty

Categories	Characteristics
I. Stable	• Few similar unchanging factors in the environment • Uncertainty can be assessed with accuracy • Forecasting tools can be used to identify patterns • Future is predictable
II. Progressive	• Several possible future scenarios • General patterns can be identified, but details such as timing and degree of events are difficult to assess • Forecasting is possible but accuracy diminishes over time
III. Dynamic	• High variety of possible future scenarios • Forecasting is possible but accuracy diminishes over time • Patterns are difficult to identify

Categories	Characteristics
IV. Unpredictable	• Futures is highly diverse • Changes can be inconceivable • Forecasting, planning and strategy as currently perceived are not relevant • Connections between causes and effects are lost

Similar to the classification of Complexity, this classification of uncertainty was used to assess the situations in the case studies and define a level of uncertainty for each case study.

4.2.3 The relationship between complexity and uncertainty

To achieve their goals, organisations require the variety in their behaviour that allows them to cope with the variety of challenges in the environment (Ashby, 1956). The variety in the behaviour of an organisation, and the ability to change behaviour, is a result of the knowledge, skills, motivation and freedom to act of its members; the way they relate to each other (structures, leadership, group relations and culture) and the infrastructure of the organisation (facilities, products, processes, machines and equipment, and information and communications systems). For the purpose of this research, this internal variety and richness of possible behaviour, and the factors that contribute to it are considered as the "complexity of the organisation". Similarly, when discussing the complexity of a department or a process, reference will be made to its internal variety.

The term "complicated" is used to refer to richness in detail, while "complexity" refers to richness in structure and behaviour. This differentiation is important because a complicated problem can be broken down into its components and each part solved by a specialist, while a complex problem has to be treated as a system, where the interaction of the components can produce 'emergent properties' that go beyond the properties of the individual components.

However, many organisational problems are both complex and complicated and it is difficult to differentiate between these two concepts. For this reason, 'complicatedness' is considered in this research as a sub-set of complexity.

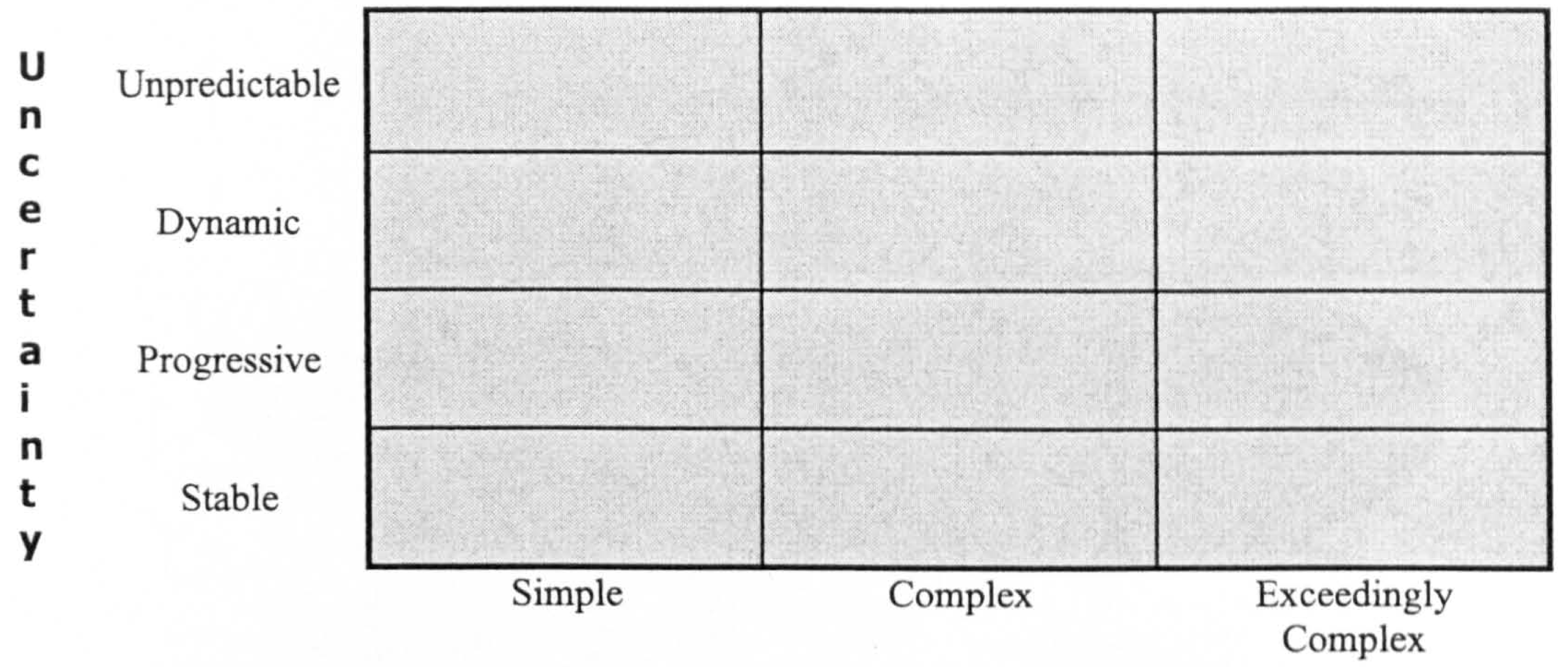
An organisation that is not capable of producing sufficient variety to adapt its behaviour to cope with challenges in the environment would not survive (Beer, 1984). This means that the complexity of an organisation needs to be aligned to the uncertainty in the environment. However, the level of complexity that an organisation should have in a certain environment does not appear to be clear from the available literature.

The Complexity-Uncertainty model presents a space where the internal complexity of the organisation and the uncertainty of the environment can be mapped. The relationship between these two variables becomes clear in the light of Ross Ashby's *Law of Requisite Variety* (Ashby, 1956), introduced in Submission 2. This law states that the variety of outcomes of a system, in response to its environment, can only be decreased by an increase in the internal variety of the system. This means that the internal variety of the system (its complexity) is used to cope with the external variety (uncertainty); in Ashby's own words, *only variety can destroy variety* (Ashby, 1956).

It is important to clarify that variety here refers to the different states that a system can exhibit in relation to its environment. This emphasises that having more products, processes or procedures does not necessarily mean that the organisation is more capable of responding to challenges in the environment.

The classifications of complexity and uncertainty presented in the two preceding sections have been used to divide the two axes of the model, breaking it up into twelve regions as shown in Figure 17.

Figure 17: Dimensions of the Model

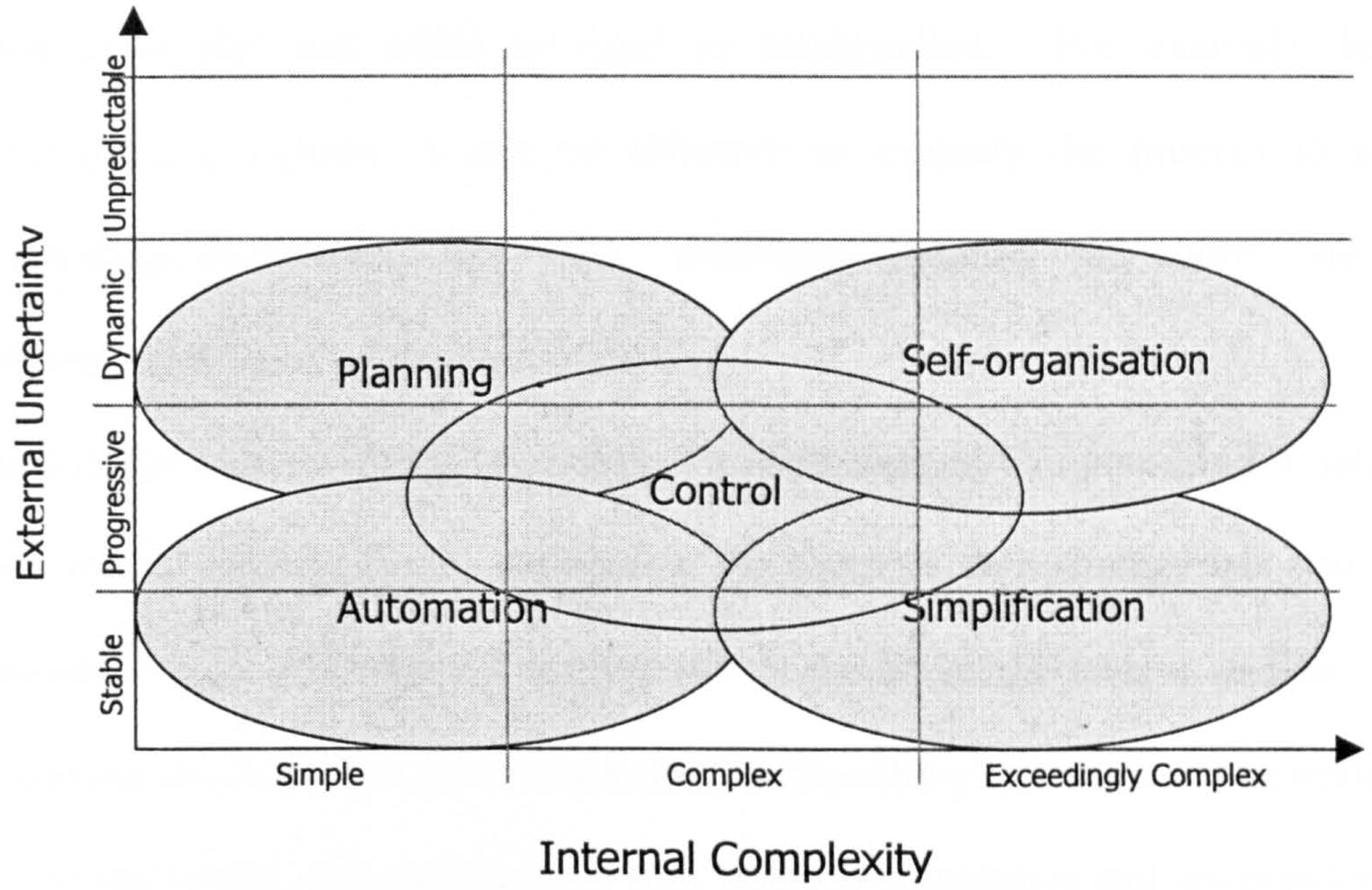


4.3 Generic Strategies

Practitioners are continually trying to find more effective and sustainable ways to design and manage organisations capable of dealing with complexity and uncertainty. However, many approaches are biased towards managing only one of these dimensions. The Complexity – Uncertainty model attempts to balance internal complexity and external uncertainty.

The case studies present a collection of approaches used to deal with complexity and uncertainty. These approaches have been categorised into generic groups of strategies that can be used in different situations. These generic strategies are automation, simplification, control, planning, and self-organisation, each represented by an oval in the model. This shape has been used to show that the strategies can overlap, like Ven diagrams, and that they can operate across different categories of complexity and uncertainty. Figure 18 depicts these strategies in different regions of the model. These strategies as well as their position in the model are the result of the analysis of the case studies, supported by elements of the literature.

Figure 18: The Complexity - Uncertainty Model



The ovals are not intended to indicate the precise boundaries of the applicability of each strategy, but to show a general trend for their effectiveness. This is also indicated by the fact that each strategy covers several regions in the model.

The position for each of the strategies indicates its ability to deal with different levels of uncertainty and complexity. For example, the automation strategy is effective for simple and stable situations, and, to a certain extent, in situations that are complex and progressive, but not in those that are dynamic and exceedingly complex.

No strategies have been mapped to the unpredictable region because none of the case studies falls into this region and therefore it is impossible to conclude about the type of strategies suitable. Evidence exists in the literature that control and planning strategies are not suitable for this unpredictable region, as it is discussed in Sections 2.4.3 and 2.5.1 respectively. There is also literature claiming that only self-organising approaches are suitable for unpredictable situations, however it is not possible to draw these conclusions from this research.

The strategies overlap in different regions, indicating that they are all linked to each other and can often be used in combination. For example, before automating a process, it can be effective to simplify the process to avoid automating unnecessary activities. Similarly, planning and control are two strategies that are usually applied jointly.

Each of the five strategies have already been discussed in submission 9, relating each one to complexity and uncertainty, furthermore each strategy has also been described from a theoretical perspective in the literature review section. The following five sub-sections are dedicated to describing how each of the strategies fit into the model and showing how they relate to complexity and uncertainty.

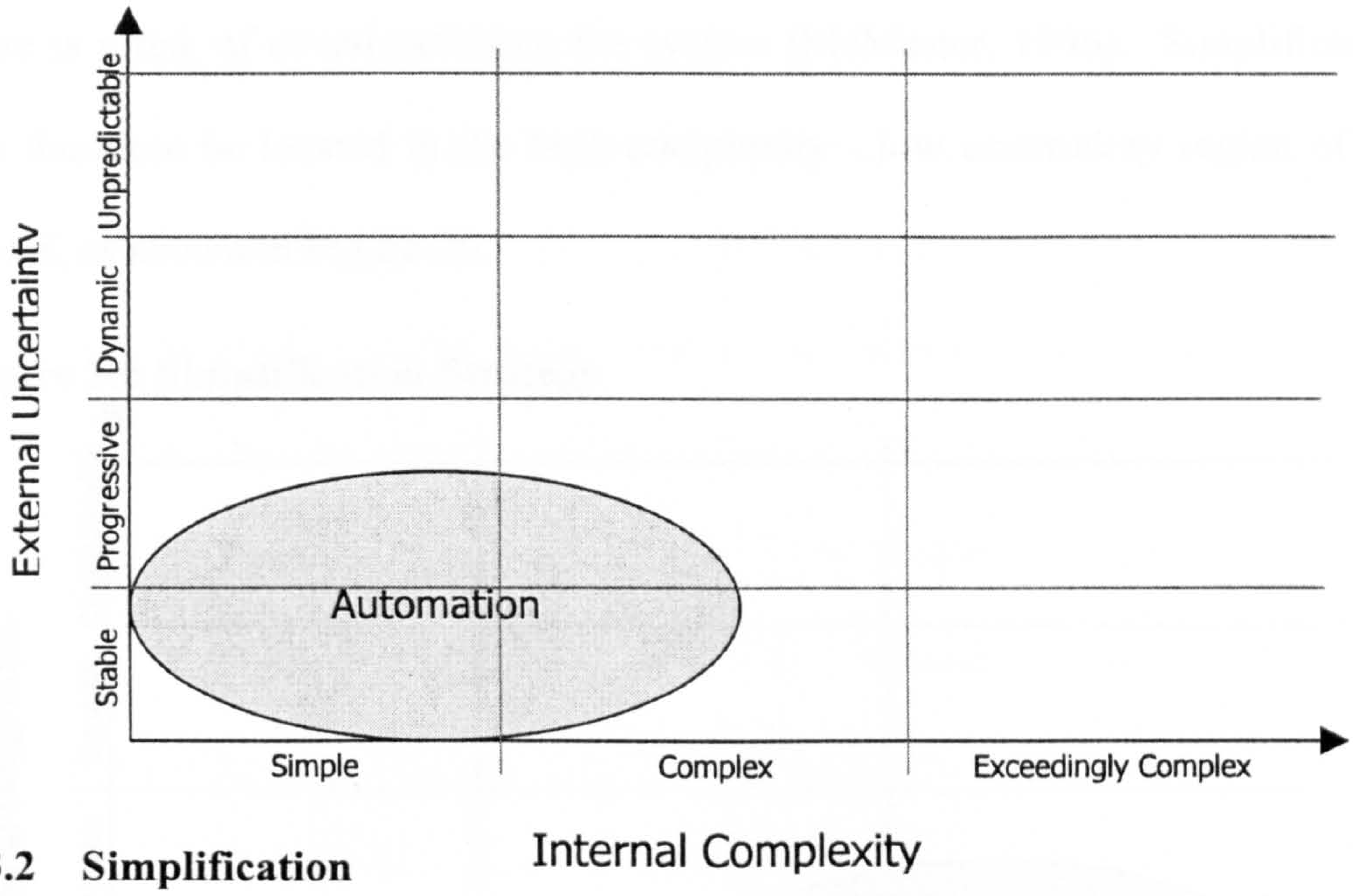
4.3.1 Automation

Automation has been defined as "the substitution of human physical and mental work by the work of machines" (Cox, et. al. 1992). As discussed in Submission 9 (section 2.1) and in section 2.4.2 of this document, automation is most effective in situations where the environment is stable, and the process or systems being automated are relatively simple.

One of the main benefits of automation is that it reduces variability in the timing and quality of outputs, however this is usually accompanied by a similar reduction in flexibility. In an environment that is relatively stable the reduction in variability would represent a benefit for the organisation, however in an uncertain environment, an organisation would require the ability to change processes and systems, and automation will represent a burden (Rommel, 1995).

To automate a process it is necessary to break it down and define all its variables. This is possible with relatively simple processes; however, there are many processes, for example creative processes, that are not simple enough to be automated. For these reasons *Automation* is located in the bottom left corner of the model as shown in Figure 19.

Figure 19: Automation Strategy



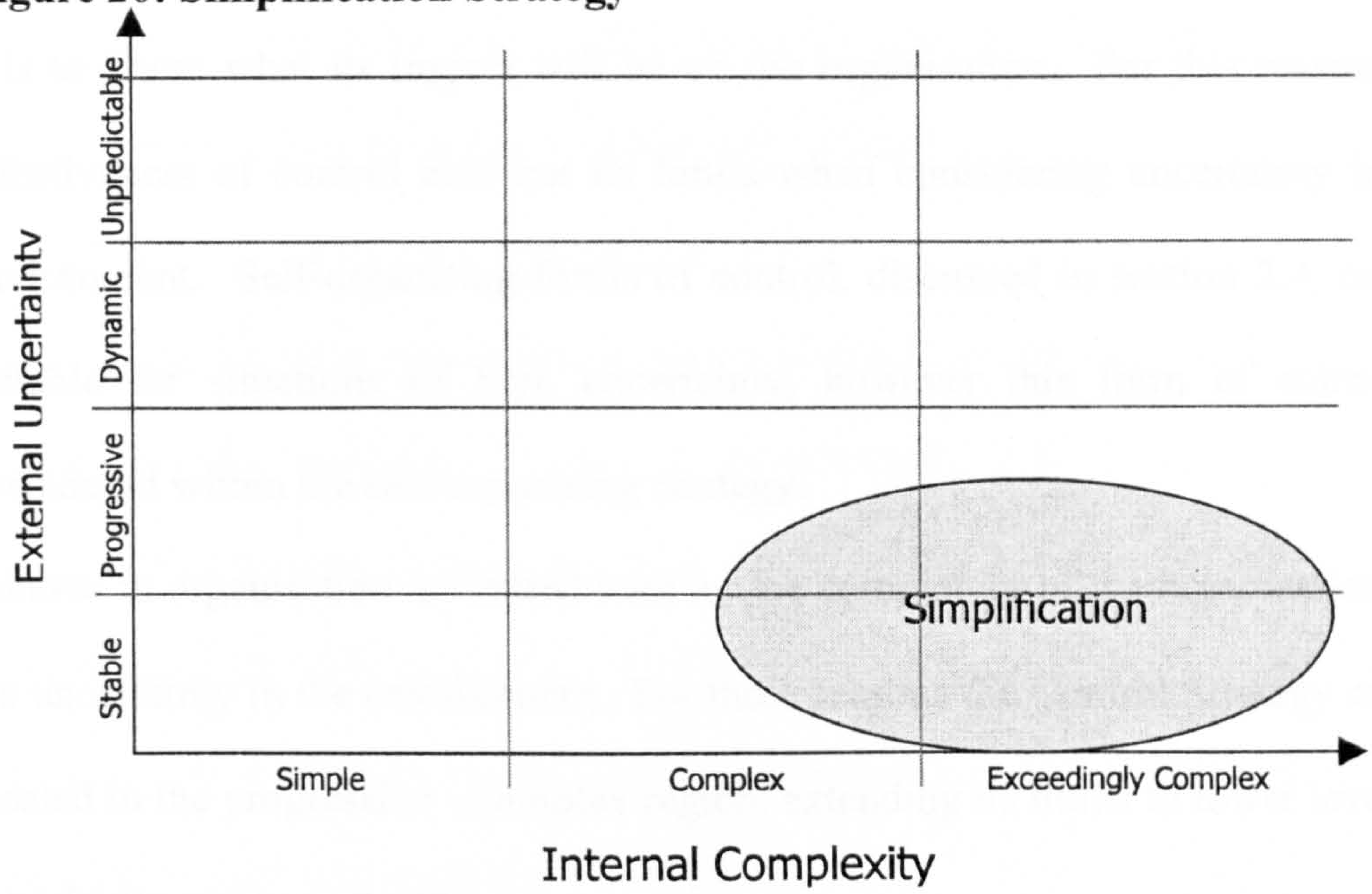
4.3.2 Simplification

Simplification has been defined as ' a strategy concerned with the removal of the sources of complexity and waste in organisations' (Gregory & Rawling, 1997). In section 2.4.1 a number of approaches to simplification have been discussed and in Submission 9, section 2.2, the relationship between simplification and the complexity and uncertainty dimensions was presented.

Simplification attempts to eliminate complexity in the system, however, a simplified system should have enough complexity to cope with uncertainty in the environment. Situations in which the environment is dynamic and unpredictable require a high degree of internal variety to respond to different situations. In these circumstances, simplifying the system would only reduce its potential to respond to challenges in the environment.

Simplification is aimed at reducing the excess complexity in the system and, in theory; it could be applied to any kind of system. The limitations of this generic strategy reside in the fact that the approach assumes that processes can be isolated, fully understood and centrally designed. However, processes tend to have many informal interactions that are difficult to analyse and document and there is a risk of oversimplifying the system (McMaster, 1996). Simplification can therefore be located in the high complexity - low uncertainty region of the model, as shown in Figure 20.

Figure 20: Simplification Strategy



4.3.3 Control

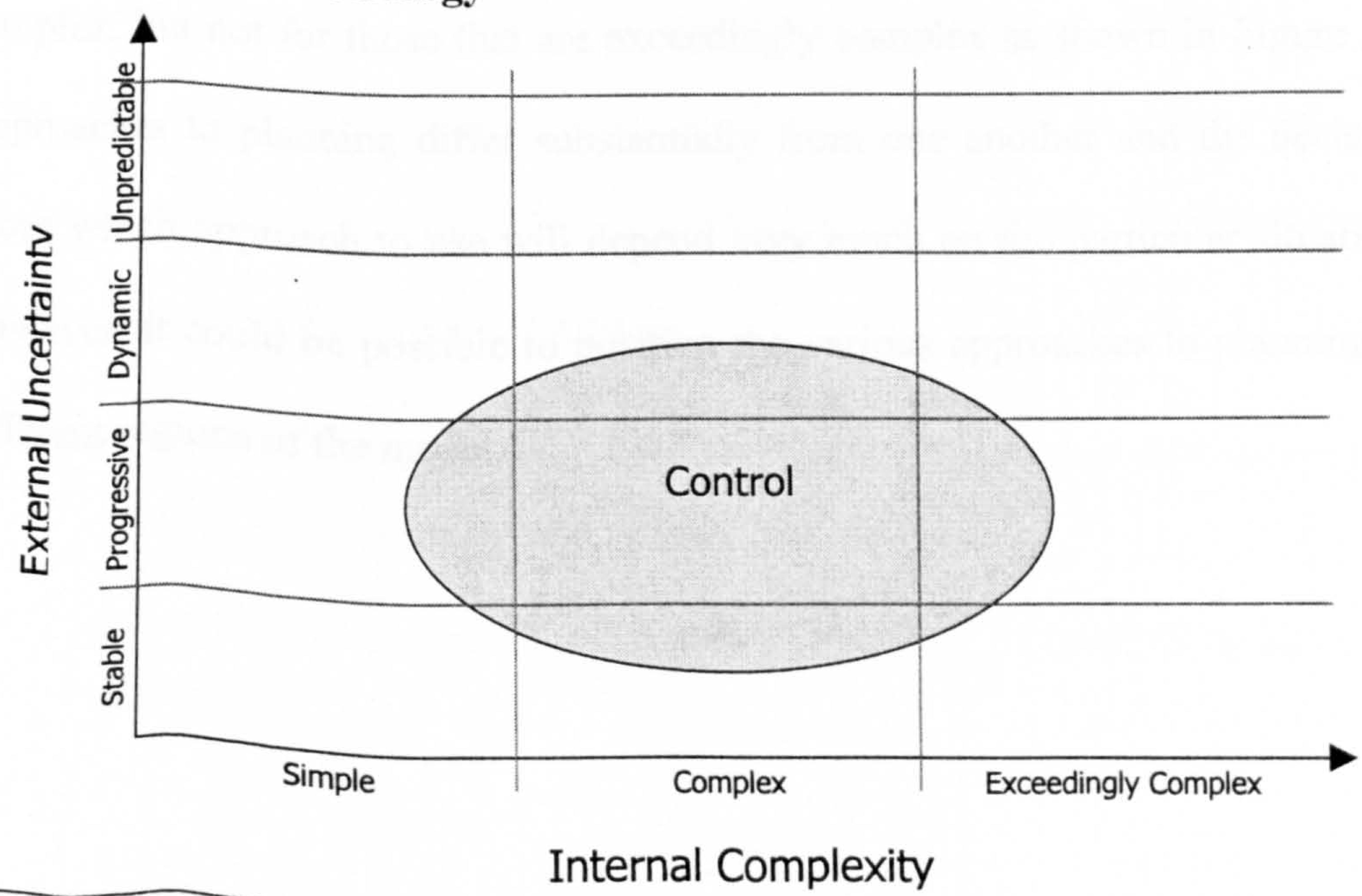
In section 2.4.3, a number of views about control were presented. Based on these views, it has been possible to define this generic strategy as 'the management approach that attempts to guide the organisation towards certain objectives, within certain limits of a standard or plan through the use of feedback.'

A control strategy can be useful in making an organisation aware of its performance and ready to act when necessary. However, the complexity of organisations makes it difficult to ensure that everything will conform to policies and procedures, because it sets limits on control. There are a number of reasons for the limitations of control such as the nature of measurement, the multiplicity of causes and effects and the diversity of objectives. These and other reasons are discussed in more detail in Submission 9 (pp. 24-25).

Organisations are measured and controlled in terms of their results, such as the quality of products, the speed of the delivery or the level of profits of the organisation. These variables are dependent not only on the organisation, but also on its environment. The more uncertain the environment, the more difficult it is to know what its impact will be on the organisation. For this reason, the effectiveness of control also has its limits when considering uncertainty in the environment. Self-organising forms of control, discussed in section 2.4, can be suitable for situations of high uncertainty, however this form of control is considered within the self-organising strategy.

Control in organisation is limited both by the complexity of the organisation and the uncertainty in the environment. For these reasons the Control Strategy can be located in the progressive - complex region, extending its limits to lower levels of complexity and uncertainty.

Figure 21: Control Strategy



4.3.4 Planning

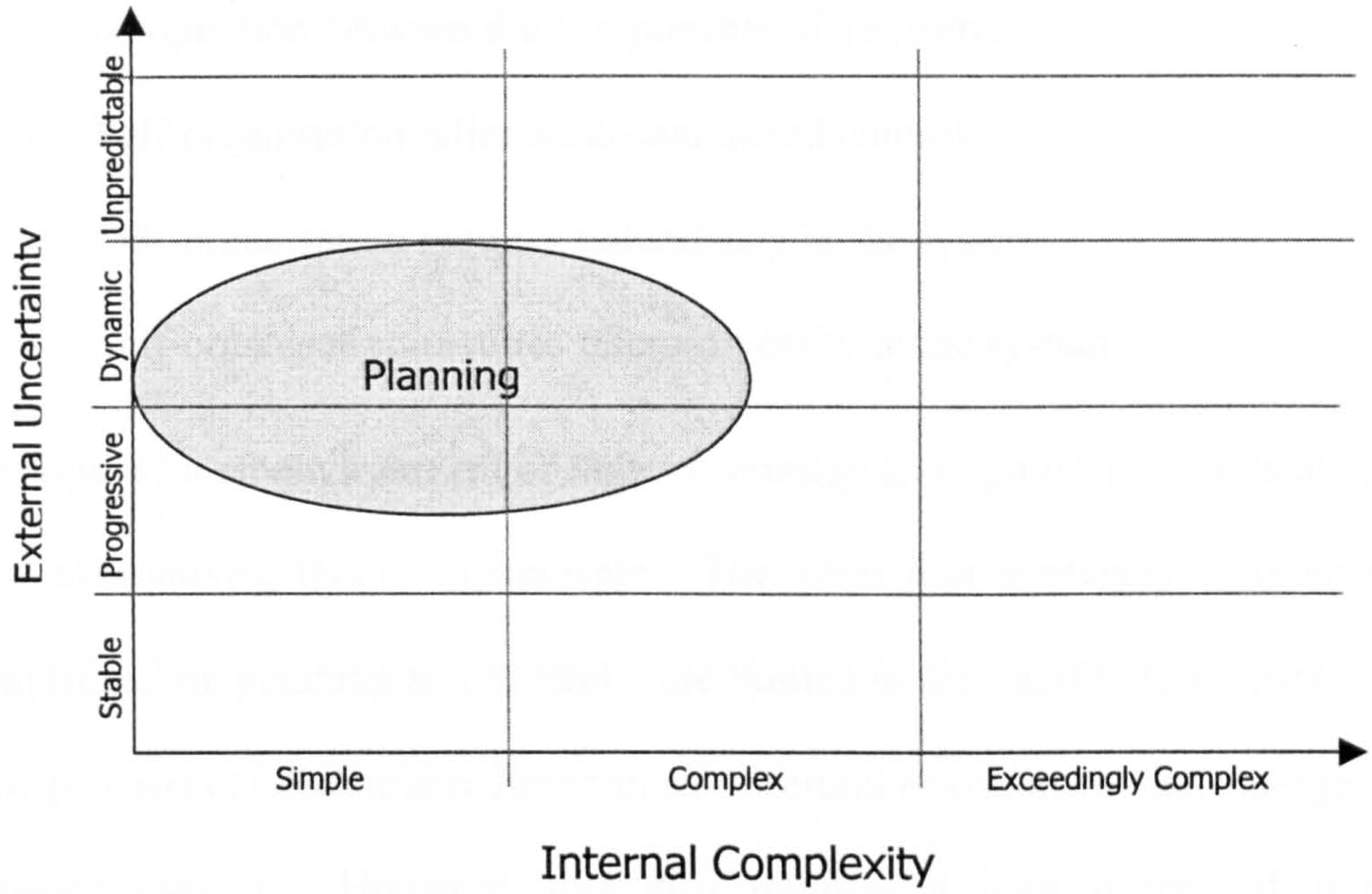
Planning has received many interpretations and many different approaches have been developed. These approaches, reviewed in Submission 9, range from rigid analytical processes to entrepreneurial and learning processes. For this research, the term planning covers this wide range of approaches intended to deal with the future of the organisation.

Planning is an outward looking strategy intended to deal with the environment. In this way, it can help organisations to understand their environment and the possible approaches that can be followed. However planning has limitations both in terms of uncertainty and complexity.

The complexity of organisations in terms of the diversity and interdependence individuals, the volatility of operating environments and the speed of change within organisations means that it is not possible to consider every single variable and scenario in a plan. Furthermore, planning presents a number of paradoxes for organisations, discussed in Submission 9 (pp. 29-32), which limit its ability to deal with complexity and uncertainty.

Planning is suitable for progressive and dynamic situations which are simple or complex, but not for those that are exceedingly complex as shown in Figure 22. Approaches to planning differ substantially from one another and the decision about which approach to use will depend very much on the particular situation. However, it could be possible to position the various approaches to planning in different regions of the model.

Figure 22: Planning Strategy



4.3.5 Self-organisation

The concept of self-organisation is the main contribution of Complexity Theory to the model, since the four generic strategies are considered part of traditional management practice. The following definition of self-organisation, provided by Stacey (1993), has been used for this research:

> "*In organisation, self-organisation is the spontaneous formation of interest groups and coalitions around specific issues, communication about those issues, cooperation and the formation of consensus on and a commitment to a response to those issues.*" (Stacey, 1993)

There are a number of key ideas behind self-organisation that have been valuable for the development of the model. These key ideas have been discussed earlier and the following is only a brief summary:

- Self-organisation can spontaneously create order, being able to produce innovation (new structure or behaviour).
- Self-organisation takes place when a system is pushed away from equilibrium

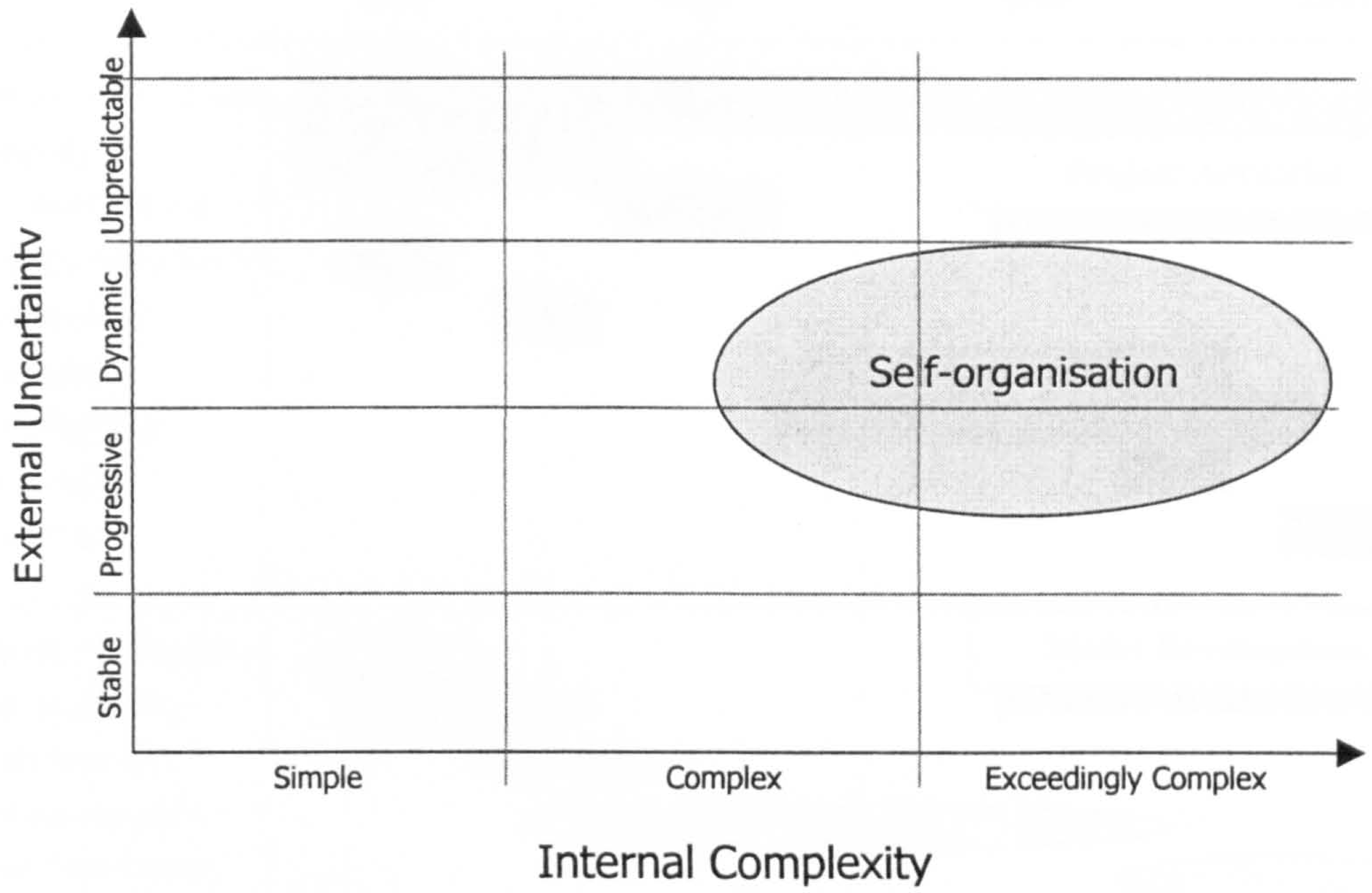
- Self-organisation is based on communication, collaboration and competition between the components of a system.
- Self-organisation relies on decentralised control
- Self-organisation requires redundancy in the system
- Self-organisation requires micro-diversity in the system

To cope with an environment of high uncertainty an organisation needs to create new alternatives; that is to innovate. The other four strategies – automation, simplification, planning and control – are limited in their ability to innovate. The new patterns of behaviour required in an uncertain environment can emerge from self-organisation. However, this also requires a high degree of internal complexity presented by way of high variety and redundancy in the system, and the ability of the components of the system to communicate and collaborate.

There are some important issues to address when considering self-organisation as a strategy for dealing with uncertainty and complexity. Firstly, there is the issue of acceptance since the ideas are radically different from those of traditional management approaches, and, according to Stacey (1993), many managers are not used to the idea that a system can control itself. Secondly, the fact that the outcomes of self-organisation cannot be predicted, making it possible to argue that self-organisation is not an intended strategy. However, the case studies have shown that organisations take actions that enable self-organisation, such as reducing the centralisation of control, and setting-up the infrastructure for individuals to communicate and interact with others, giving them the freedom to make their own decisions in collaboration with other colleagues.

Self-organisation has been collocated at the progressive – dynamic and complex – exceedingly complex region of the model, as can be seen in Figure 23.

Figure 23: Self-organisation Strategy

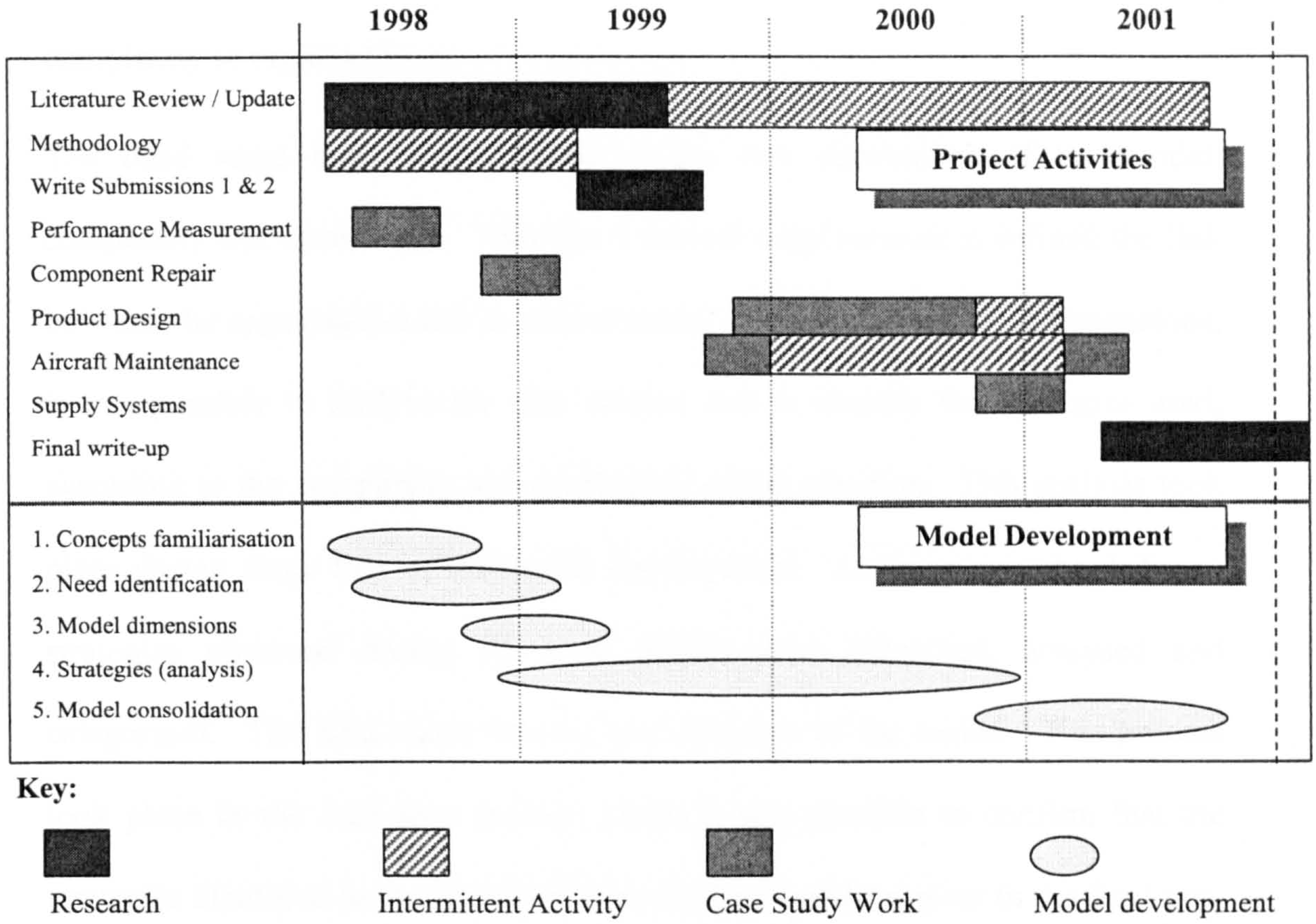


A number of authors have suggested that self-organisation can help organisations to cope with unpredictable change. This model does not intend to deny this, however, there is no evidence in the case studies of situations of unpredictable change and hence it is not possible to draw any conclusions in this regard.

4.4 The Evolution of the Model

The creation of the model was an evolutionary process in which a number of ideas were combined, adapted and selected before arriving at the final model. The diagram in Figure 24 shows a high level Gantt chart of the project, outlining the main activities. The bottom half of the chart shows the main stages of development of the model, depicting the process of evolution. The figure is followed by an explanation of the different stages of development and how they link to the activities of the project.

Figure 24: Project Evolution



The chart shows five stages in the development of the model: concept familiarisation; need identification; model dimensions; strategies analysis and model consolidation. The first stage, concept familiarisation, took place at the initial stages of the project when the researcher was investigating the different concepts and approaches embraced by Complexity Theory. The main input during this first stage was the literature review.

The second stage, need identification, refers to the recognition of the need for a model to manage complexity in organisations. This was the result of discussions during the first two case studies, where participants stated that they would find it useful to have a model that could help them to manage complexity. While many of the approaches found in the literature opted for the elimination of complexity, Complexity Theory presented a different view and this was seen as an opportunity for creating a more comprehensive model of how to deal with complexity in organisations.

The third stage was the definition of the two dimensions of the model, complexity and uncertainty. This was a critical stage because it defined the link between the organisation and its environment. Having defined these dimensions, it was possible to analyse the case studies and to identify the strategies used, according to the complexity and uncertainty of the situation. This analysis took place during stage four of the model development. At this stage, the different strategies observed during the case studies were identified, analysed and categorised. The final stage was the consolidation of the model. This process took place in the final case studies, where it was possible to confirm that the strategies identified in the first three case studies would reappear in the final two. Moreover, the case study conducted with Ford presented an opportunity to verify that the strategies were also valid in a different industry.

4.5 The Nature of the Model

A model is a representation of reality which focuses on only a few dimensions or variables which are of interest. Models help to understand the complexity of reality and represent a particular way of thinking about a phenomenon. However, since they only represent one perspective, they can never represent a complete situation (Boody, 2002).

Management models can be prescriptive, providing specific guidelines and paths of action, and descriptive, uncovering the current structure or behaviour of a system. An example of a prescriptive model would be a computer program that calculates the route from a point A to point B based on an algorithm and a series of parameters. A descriptive model would be a map that represents an area covering both points A and B, where the user would need to analyse and decide on the route to be used. Both models can help the user to get from A to B, however the software provides the solution while the map allows understanding, opening a number of alternatives but not providing solutions. The models also require different degrees of analysis by the user and provide different degrees of flexibility. In management, models such as Fayol's principles of management, Operations Research models and Design of Experiments approaches, provide clear guidelines on how things have to be done and tend to prescribe a single solution for a problem, falling into the prescriptive category. On the other had models such as open systems models and contingency models fall into the descriptive category.

The Complexity – Uncertainty model does not give solutions, it provides understanding, and based on the descriptions provided would fall into the descriptive category. The model describes certain trends that relate uncertainty in the environment to the internal complexity of an organisation. These trends can help in understanding how the use of certain generic strategies is more suitable. However, the generic strategies are only guidelines which cater for a wide range of alternatives. Furthermore, for most situations a number of generic strategies are suitable, opening even further the range of alternatives available.

The term descriptive, however, seems somewhat limited in portraying the potential of the Complexity – Uncertainty Model, since it not only describes the situations, but also helps in understanding and learning about them, presenting different alternatives for action. Perhaps a better term to describe the Complexity – Uncertainty model is as a Learning model, that can help people gain a better understanding about their organisations and learn about the different approaches suitable under different situations. Another suitable term would be a contingency model, since it tries to 'understand and explain how organisations function under different situations' (Lawrence & Lorsch, 1967).

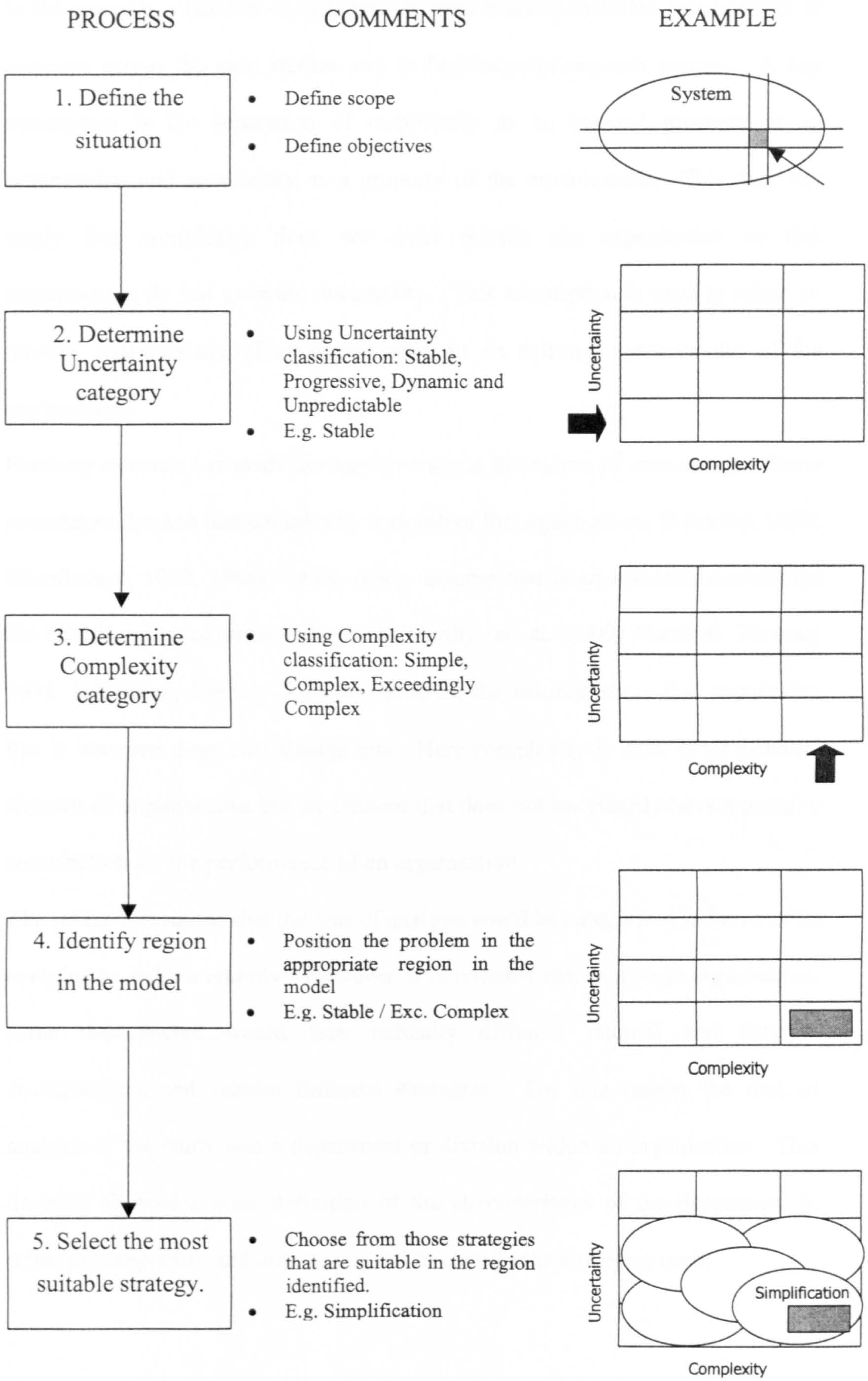
4.6 The Use of the Model

The model can help to identify the most suitable generic strategies for a particular situation. This is done by following the five-stage process depicted in Figure 25. The process starts by defining the scope of the situation; this allows the analysis to be focused only on those elements of uncertainty and complexity that affect the problem. Uncertainty is assessed in stage 2 using the classification stable, progressive, dynamic and unpredictable. In the example presented in Figure 25, the "stable" category has been selected. In Stage 3 complexity is assessed using the complex and exceedingly complex classification. In the example, the exceedingly complex category has been selected.

Once the levels of uncertainty and complexity have been assessed, it is possible to identify a region in the model. The Stable – Exceedingly Complex region has been selected in the example. Finally, it is possible to determine the strategy or strategies that are most suitable for the problem. In the example, a simplification strategy appears to be the most suitable.

The process described in this section defines a structure that should be followed so that the model can be applied. However, from the experience of the case studies, it was found that practitioners tend to have a good understanding of the complexity and uncertainty of the problems they are facing and it was relatively easy to position the problem in a region of the model, so that suitable strategies could be identified almost immediately. Section 5 presents the positioning of each of the case studies on the Complexity-Uncertainty.

Figure 25: Using the Complexity - Uncertainty Model



4.7 Model Assumptions

In the research, a number of assumptions were made to maintain homogeneity of concepts across the case studies and to facilitate the research process. A key assumption is the separation of complexity as an internal property of an organisation and uncertainty as a property of the environment. This does not imply that complexity does not exist outside the organisation or that organisations do not generate uncertainty. This assumption is used to relate an internal characteristic of an organisation to an external characteristic of the environment.

Previous research has made assumptions about the nature of complexity. Some researchers assume that complexity is negative for organisations (Rommel, 1995; Shomberger, 1982, 1986), whilst others assume that is an essential element for the sustainability of organisations (McCarthy, et. al. 2000; Maira & Thomas, 1998; Kauffman, 1995a). For this research, the assumption is that complexity lies in between these two standpoints. Here complexity is seen as an essential element of organisations but an element that does not necessarily have a positive contribution for the performance of an organisation.

The research assumed that the unit of analysis could be categorised in terms of its complexity and uncertainty. However, it is possible that in a large organisation, some departments would face radically different internal and external circumstances and require different strategies. For this reason the unit of analysis of the study was a department or division within an organisation. This decision allowed a clear definition of the characteristics of the department in terms of complexity and uncertainty and to classify the strategies used.

The model also assumes that the generic strategies operate within a certain realm. This only means that these strategies tend to be more effective under a certain circumstances, not that these strategies cannot be used in other conditions.

5 Case Studies Discussion

This section presents a summary of the five case studies that constituted the research. Each of the subsections is dedicated to one case study, presenting an introduction to the project, a description of the contributions to the research and the contributions to the organisation. Individual reports for each case study are presented in Submissions 4 – 8 of the portfolio

The Complexity-Uncertainty model was developed based on the literature and contributions of the first three case studies; the final two cases were used for validation. In the analysis presented here the model has been used retrospectively to look at the first three cases from the same viewpoint as the final two. The cases are presented in chronological order.

5.1 Performance Measurement Project

This study was conducted in collaboration with Susan Grinsted at what was the Commercial Division of British Midland Engineering (now Engineering Division of "BMI British Midland International PLC") from April to August 1998. The full report is presented in Submission 4 "The Development of a Performance Measurement system for British Midland Engineering".

British Midland Engineering was the aircraft maintenance and technical support arm of the airline, and its main objectives were to ensure the safety and availability of the aircraft. These objectives require returning the aircraft from maintenance in perfect condition as fast as possible. The Engineering division was broken down into two main departments, Technical and Commercial. The Technical department was in charge of the maintenance and repair operations and the Commercial department focused on sourcing, warehousing and supplier development. The Commercial division was the focus of the research.

This was the first case study and the goals were to understand what strategies were used by British Midland, and specifically the Commercial Division, to deal with complexity and uncertainty. From the companies' perspective there was another objective, which was to develop a performance measurement system that could reflect achievement, against the mission and objectives of the division.

Data was collected through interviews with managers, operators, internal customers, and suppliers. Data collection included internal data about processes, information requirements, and external information about the services provided by the Commercial Division and the relationships with the environment.

5.1.1 Contributions to the Organisation

The Commercial Division required a complete measurement system that could reflect performance and help to monitor and control the operation. This not only required the designing of a new report, but also the entire set of procedures to generate the measures; the sources of data and the implementation of the system. This required the following five deliverables:

- a set of performance measures to meet the mission and objectives of the Commercial division;
- a proposal for the format and content of the monthly report;
- a list of data items required to produce each measure of performance and the points of collection;
- the procedures required to produce performance measures from data;
- the implementation of these procedures to produce the first report.

The proposal for the measurement system included two sets of measures: one for the management team, and a second aimed at the different functional areas within the Commercial department, with the purpose of helping the people in these areas to analyse and improve their performance. Table 16 presents a summary of the performance measures suggested for the management team.

Table 16: Framework of Performance Measures

FINANCIAL	CUSTOMER SERVICE
• Inventory Value • Cost of Shortages • Price Change • Direct Maintenance Cost (DMC) • Capital Expenditure • Total People Costs • Transport Costs • Cash Flow	• Final Users and 3rd Party Customers o Delays and Changes to schedule o Carried Forward Defects (CFD) • Internal Customers o Carried Forward Defects (CFD) o Delays and shortages o Kit Robberies o Level of pre-load o Service level of non-pre-loaded parts o Queues at counter
INTERNAL BUSINESS	**CONTINUOUS IMPROVEMENT**
• Service Levels • Efficiency (People / amount of work) • Stock Turns • % of Active Stock in a time period • Stock accuracy • Cycle times and Rotables Turnaround	• Supplier development program • CFD Spares Analysis (Cause – Effect Analysis) • Level of Integration • Employee Moral • Suggestions Scheme • Employee Performance Evaluation

The performance measurement system was tested by elaborating the first report, ensuring that all the information required was available and that the information presented was acceptable to the management team. Barriers to the future use of the system were identified and appropriate recommendations were made.

The system helps to monitor and control performance, since it enables the identification of the root causes of problems and the understanding of the relationships between variables. Furthermore, the system can help to identify and prioritise improvement areas.

5.1.2 Contributions to the Research

This first case study was carried out at a very early stage of the research, when the theoretical research regarding the model was under development. At this stage, the case study presented an opportunity to observe some traditional approaches for dealing with complexity and uncertainty. These observations were analysed at a later stage to ensure that the strategies used in this case study were consistent with the model.

One of the initial findings in this case study was that managers within the Commercial Division lacked some of the information they required for making decisions. In particular there were three main areas where a lack of information was perceived: (1) inventory management, in terms of the value of the stock and efficiency, (2) cycle time for rotables, this is the time that it takes to have rotable components repaired by sub-contractors and returned to serviceable stock, (3) purchasing information, in terms of the effectiveness and efficiency of the buyer-supplier relationship. The unavailability of information was not the only problem, there was also a lack of confidence in the information that was available. Managers perceived the inaccuracy and lack of information as uncertainty.

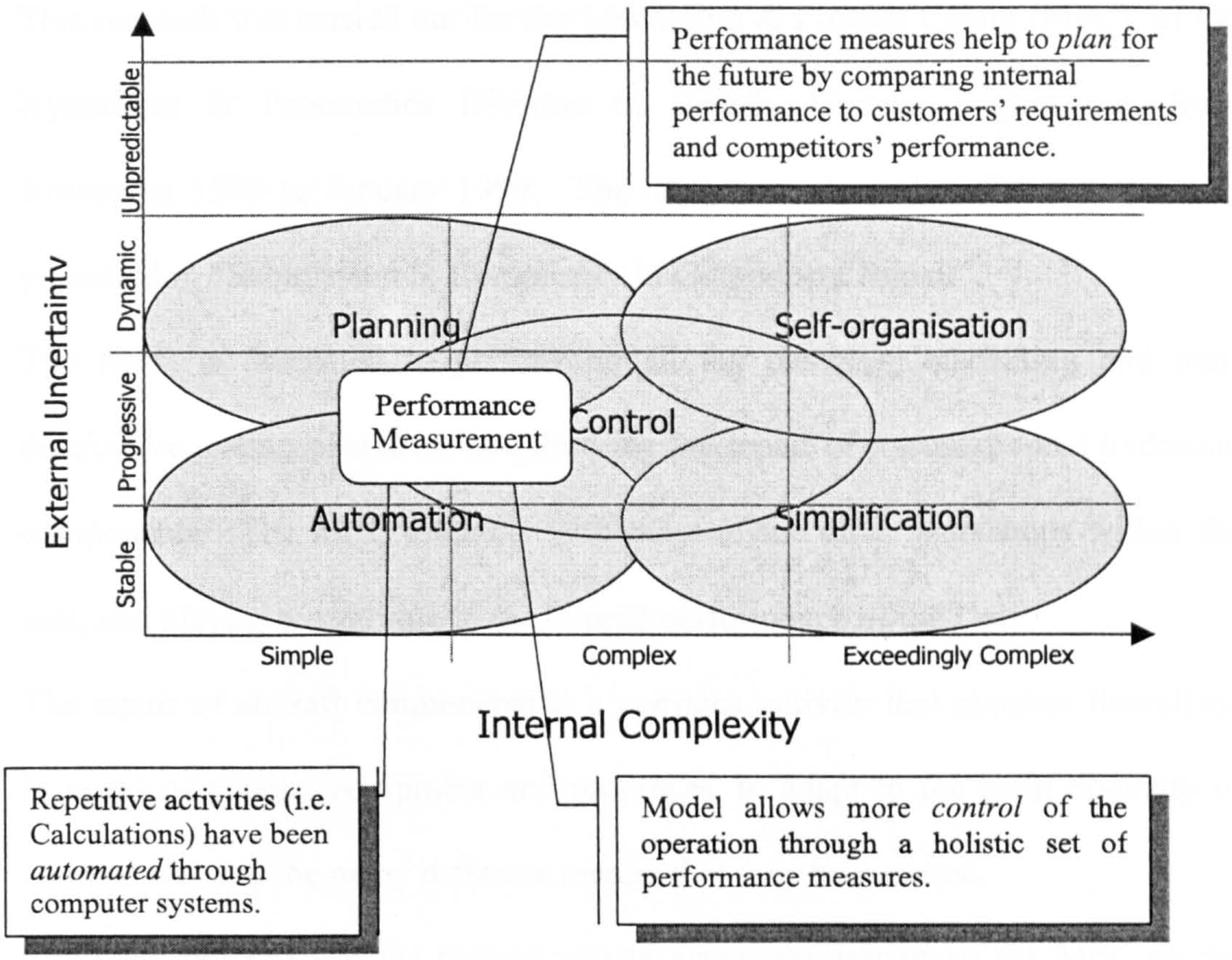
Lack of information was not the only source of uncertainty in the Commercial Division. For example, forecasting component failure using reliability information, provided only an estimation which is subject to uncertainty. Similarly, supplier delivery times, particularly for the repair of rotable components, have a certain degree of variability. It is possible to find patterns in these measures allowing forecasting within certain limits and for a certain period of time. However, precise details about the timing and degree of events are difficult to assess. These are the characteristics of the *Progressive* category of uncertainty, where this project has been positioned.

The diversity of components in an aircraft and the existence of various suppliers for every component are important elements contributing to complexity in the maintenance and stock management processes. This is complicated even further by the fact that many components can perform the same function and therefore can be interchanged, usually known as "alternative parts". At the time that this project was conducted there were around 100,000 different components in the computer system in British Midland, of which around 20% were classified as alternative parts. These elements of complexity within the Commercial Division do not fit precisely any of the categories of complexity defined in the previous section. On the one hand a large number of components is managed, however in terms of people the department is relatively small and interdependences do not appear to be strong, for this reason it was decided to locate this project in between the *simple* and *complex* regions in the internal complexity axis.

The situation was approached with the development of a performance measurement system that covered both internal and external measures. This represented essentially a control strategy that could help people to monitor performance and assess which variables were affecting it, providing more information to support decisions. This in turn could also support a planning strategy in which targets and continuous improvement programs could be agreed from the different measures. Furthermore, the performance measures can be compared to competitors' performance or to customer requirements in order to determine the future direction of the organisation. An automation strategy was also applied, to eliminate some of the repetitive activities that would be required every time the report was produced.

Figure 26 maps the strategies followed in this project to deal with uncertainty and complexity, providing a brief explanation for the use of each strategy.

Figure 26: Generic Strategy Analysis - Performance Measurement Project



Automation, control and planning have their limitations and cannot eliminate uncertainty in the environment. However, the measurement system can help to reduce uncertainty generated by the inaccuracy and lack of information.

The development of the model was a continuous process throughout the research and the classification of strategies was not immediately apparent at the time that this project was conducted. However, by analysing the information obtained in this project retrospectively, it was possible to classify the strategies into automation, planning and control. An important development at this stage was the realisation that, even though these traditional approaches can be effective in some situations, there are limits to what could be planned and controlled.

5.2 Aircraft Component Repair Project

This research was carried out for the Machining & Process Centre (MPC), of the Hydraulics & Pneumatics Division of British Airways Engineering, from November 1998 to January 1999. The analysis and results of this project are presented in "Submission 5: Complexity in Component Repair".

The MPC is dedicated to performing all the cleaning, machining and non-destructive testing operations required for the repair of pneumatic and hydraulic components. The MPC interacts with most of the other workshops within the unit, and plays a central role in the overall performance of the Unit.

The repair of aircraft components is a complex activity that requires flexibility, in terms of people, equipment and processes, to adapt to the great diversity of components and the many different repairs that may be required.

The main objective of the project was to assess the impact of the MPC on the performance of the division, and to identify areas of improvement, focusing, in particular, on cycle time reduction.

The research involved an analysis of the MPC from a systems perspective, looking at its internal processes, workforce, equipment, and its relationship to the environment, with the aim of understanding the approaches that can be followed to deal with the complexity of the operation and to identify potential areas of improvement for the workshop. Different approaches were used in this analysis: a statistical analysis of various indicators helped to understand performance trends within the workshop, process analysis tools were used to breakdown the processes and identify non-value-added activities and bottleneck resources, and the human perspective was considered by looking at the perceptions of both customers and employees.

5.2.1 Contributions to the Organisation

A number of areas of opportunity for improving performance at the MPC were identified, and a series of actions required to exploit these opportunities were devised. A summary of these areas of opportunity is presented in Table 17. A full section detailing the areas of opportunity, support information and recommended actions is presented in Submission 5 section 7.

Table 17: Areas of Opportunity for the MPC

Areas of Opportunity	Actions
1. Process ▪ Delays along the process ▪ Changes of ownership ▪ Low value added time	▪ Make operators responsible for entire process ▪ Send complete tasks to sub-contractors ▪ Work towards a more flexible workforce
2. Planning, Scheduling & Sequencing ▪ Sequencing rules are not focused on reducing Time or WIP ▪ No use of MRP capabilities ▪ Limited forecasting	▪ Develop a sequencing and prioritisation system that also considers time ▪ Update BOMs and Stage Sheets before Movex (MRP II) is implemented ▪ Record standard times to exploit forecasting and scheduling capability
3. People ▪ Overtime dependence ▪ Fear for job security ▪ Lack of workforce flexibility	▪ Training on critical resources ▪ Remove cultural constraints for the reduction of TRT and WIP
4. Bottleneck Resources ▪ Jig boring and grinding are bottlenecks ▪ Bottlenecks are not fully utilised ▪ Few people know how to operate bottleneck resources	▪ Initiate a Set-up-time reduction programme ▪ Train enough people to backup bottlenecks ▪ Investigate possibility of offloading work from Jig borers to other resources
5. Performance Measurement ▪ TRT suffers when 'old' components are finished ▪ WIP promotes processing parts with short processing time ▪ Availability of components in stores is not considered ▪ Cost measures such as value and float of components are not considered	▪ Establish *Total Queue* measure (sum of queuing days for all components in shop) as the only measure of time and stock. This promotes the reduction of overall queue and therefore the reduction of both TRT and WIP.
6. Cleaning & Crack Check ▪ TRT is long and with little VAT ▪ Components get lost or mixed up ▪ Internal problems between workers. ▪ Workforce needs close supervision ▪ Other shops ask for maintenance workers help in other tasks ▪ Possible hidden demand	▪ Start a project aimed at delivering a quality "next day service" ▪ Closer supervision (at least initially).
7. Sub-Contracting ▪ Relatively high proportion of WIP is held at sub-contractors (16% on average, up to 25%) ▪ Sub-contracting can replace overtime	▪ Develop criteria for the use of sub-contractors based on workload and capabilities. This can be used to balance the use of overtime.

This project did not involve the implementation of the recommendations shown in the table. However, when implemented they could achieve savings in terms of people and subcontracting, reduce turnaround time and produce a more effective use of resources. Improving turnaround time could not only help to provide a better service to internal customers, but could also provide a justification for the reduction of the inventory of parts required in the system and hence a reduction in investment. These recommendations have the potential of improving key performance indicators of cost, service and inventory.

5.2.2 Contributions to the Research

The main strategy used by BA before the study was one of *control* where measures such as turnaround-time and work in progress (WIP) are used to try to maintain the operation within certain limits. However, this control strategy was perceived as insufficient for coping with the variety of requirements. The original scope of the project focused on a *simplification* strategy to deal with the elements of non-value added time in the process.

The research revealed that the MPC did not have any tools for *planning* the operation. Work was undertaken on a day-to-day basis without any visibility of the future workload. Actions were recommended to exploit the planning, forecasting and scheduling capabilities of Movex, a new MRP II system under implementation.

Control and simplification were the main strategies used by the company to deal with complexity and uncertainty at the time of the study. During the research planning was identified as another potential strategy. However, the retrospective use of the Complexity-Uncertainty model revealed further opportunities for the MPC, but first it is necessary to locate this case study in the model.

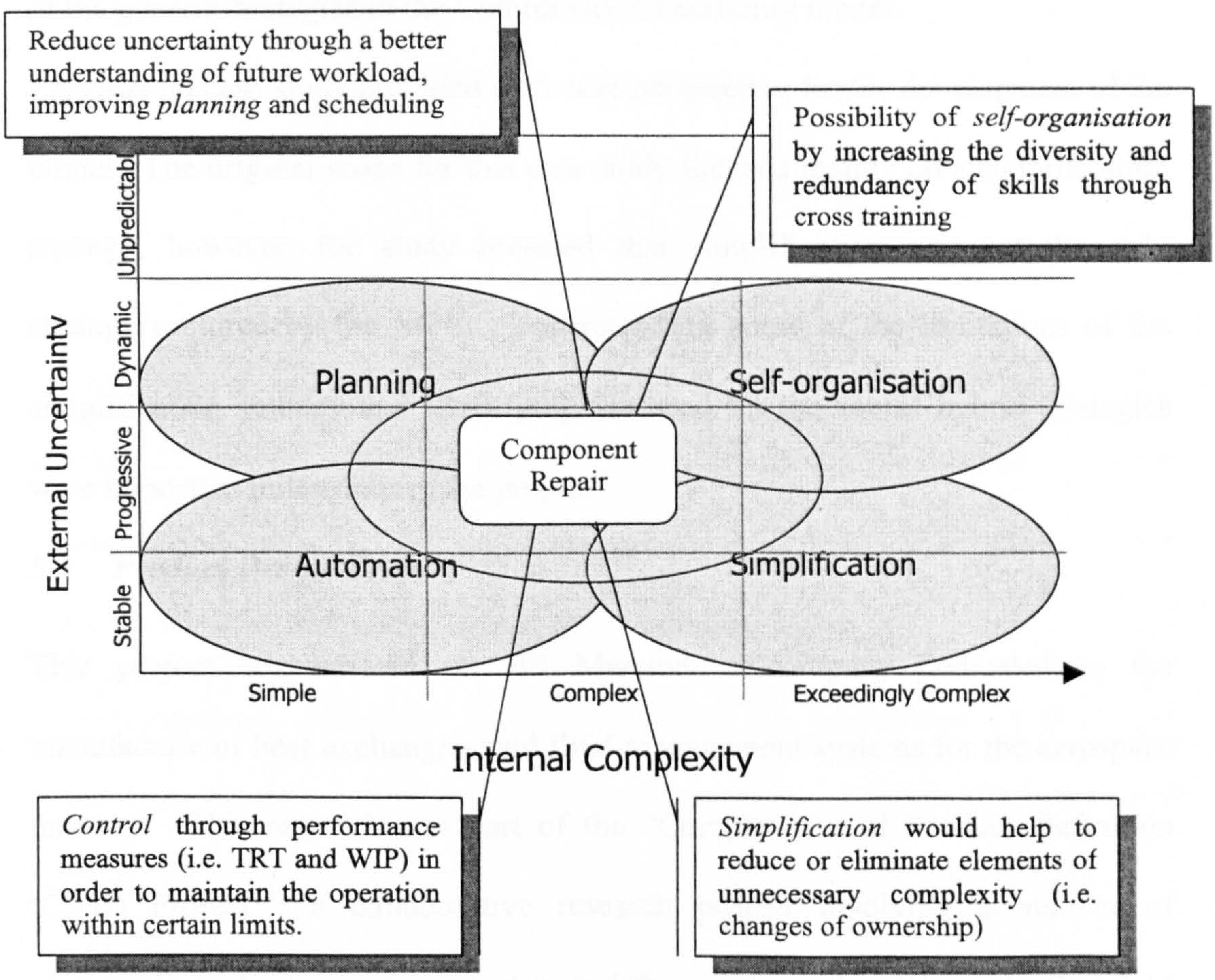
The MPC operates like a job-shop, with a wide variety of work requirements due to the large number of components and the diversity of 'problems' that need to be fixed. The precise tasks required for repairing each component are unknown, until the component is inspected and the fault(s) are identified, this implies a high degree of uncertainty, however, it is known that most components will need to be measured, cleaned and crack-checked, allowing some degree of planning.

Another element contributing to uncertainty at the MPC is the lack of visibility of future workload, and the lack of knowledge of the float of components in the system. The MPC therefore works on a day-to-day basis with little understanding of future requirements. Finally, sub-contractor deliveries and equipment reliability also contribute to uncertainty in the operation.

At the MPC it has been possible to identify certain patterns and trends which make forecasting possible. Short term demand forecasts could be very accurate because most components arrive at other areas of the P&H division before making their way to the MPC, however, even with reliability figures, it is difficult to forecast the medium and long term demand for components. Furthermore, predicting certain disruptive events, such as the appearance of a Concord component, are impossible to estimate precisely in terms of time. Therefore, the level of uncertainty at the MPC has been classified as *progressive.*

This variety in demands that is placed on the MPC requires a similar degree of internal variety in terms of skills and equipment including flexibility and adaptability to cope with the demands. The activities required to repair a component are closely interrelated and a standard sequence is usually required. For example, a component might need to be cleaned, measured, machined, cleaned (for a second time) and crack checked before it leaves the MPC. These activities are interdependent, increasing the complexity of the operation. The system has large number of components and interrelationships, however it is still possible to describe the processes and interactions in detail, and it is possible to predict, to a certain degree, the behaviour of the system, for these reasons it has been classified as *complex*. Figure 27 positions this case in the Complexity – Uncertainty model and presents the three strategies used, planning, control and simplifications as well as self-organisation.

Figure 27: Generic Strategy Analysis – Component Repair Project



The retrospective use of the model in this case indicated that *self-organisation* was a potential strategy. At the time of the study the workforce was very specialised, knowing only how to operate one or two of the machines, leaving little scope for switching people between resources. A multi-skilled workforce could provide a completely different approach to the operation in which people could take full responsibility for the repair of a component. Cross-training would increase the variety and redundancy of skills within the department so as to enable the self-organisation of people around the work required.

An important development for the model that took place during this case study was the identification in the literature, of two methods for classifying strategies for eliminating time wasted in the processes. These two methods, developed by Handfield (1995) and by Gregory & Rawling (1997), helped in the classification of the generic strategies in the Complexity-Uncertainty model.

This second case study provided a broader perspective for the development of the model. The original scope for this case study focused mainly on a simplification strategy, however, the study revealed that simplification was not the only strategy required by the MPC. Understanding some of the limitations of the simplification strategy and identifying the need for the use of hybrid strategies were important milestones in the project.

5.3 Product Design Project

This project concentrated on HS Marston, a company dedicated to the manufacture of heat exchangers and fluid management systems for the aerospace industry. This research was part of the "Complexities of Product Definition (CXD) Project"[1]; a collaborative research project involving a number of companies in the aerospace industry, and three universities, Warwick, Cranfield and the London School of Economics. The period for conducting this project was from September 1999 to February 2001.

[1] Supported by the UK EPSRC Council under grant # GR/M23649 and GR/M24226

The objective of the research was to analyse new product development as an evolutionary process, looking for a better understanding of the dynamics of innovation that could help to improve design strategies. The full report for this project constitutes "Submission 6 – Complexity in Product Design"

The new product development process (NPD) at HS Marston was mapped and analysed, and this information was used as input for the development of a simulation model programmed in Visual Basic. The simulation was based on a Genetic Algorithm that emulates product development using evolutionary elements such as selection, crossover and mutation to evolve product concepts until a single concept is selected. Design of experiments was used to examine the results of the simulation.

5.3.1 Contributions to the Organisation

This research identified a number of similarities between product design and the process of natural evolution. Analysing NPD in this context could lead to a better understanding of product development and to the identification of more effective strategies for satisfying customers' demands.

The experiments performed helped to confirm the importance of time and diversity of design in product development and to highlight the importance of learning, particularly in situations where an organisation is being challenged to expand its knowledge base. A number of approaches, summarised in Table 18, were suggested to exploit these areas of opportunity.

All of the methods, analysis, results and learning points of the project have been detailed in a report that was published on a CD-ROM and presented to all the companies involved in the CXD project.

Table 18. Areas of opportunity for HS Marston

Area of Opportunity	Actions
Process cycle time	**Cycle time reduction:** Identifying and eliminating non-value added activities in the process helping to reduce the total development time. Similar approaches have shown results in reducing time to prototype at Rolls Royce aerospace (Litchfield, 1995) **Collaboration:** Closer collaboration with customers and suppliers would help the organisation to be proactive in their product design process and to reduce uncertainty.
Diversity of concepts	**Collaboration:** producing a diversity of designs can be prohibitive for a company of the size of HS Marston, however closer collaboration with business partners and even competitors could help them to test a wider variety of product concepts, increasing the possibility of producing a suitable design.
Learning and knowledge management	**Training:** the use of formal training programs and on the job training would help to develop the skills and knowledge of people, ensuring that they are aware of leading edge technology in critical areas and provide continuous development. **Job retention:** it can take a long time for the personnel to develop the knowledge and skills necessary for designing a heat exchanger. The organisation should provide the incentives for people to remain working with the company **Information Technology:** It was found that knowledge developed in previous design projects is often lost due to the lack of a system that allows information sharing and retrieval. IT systems could provide a suitable solution to address this problem.

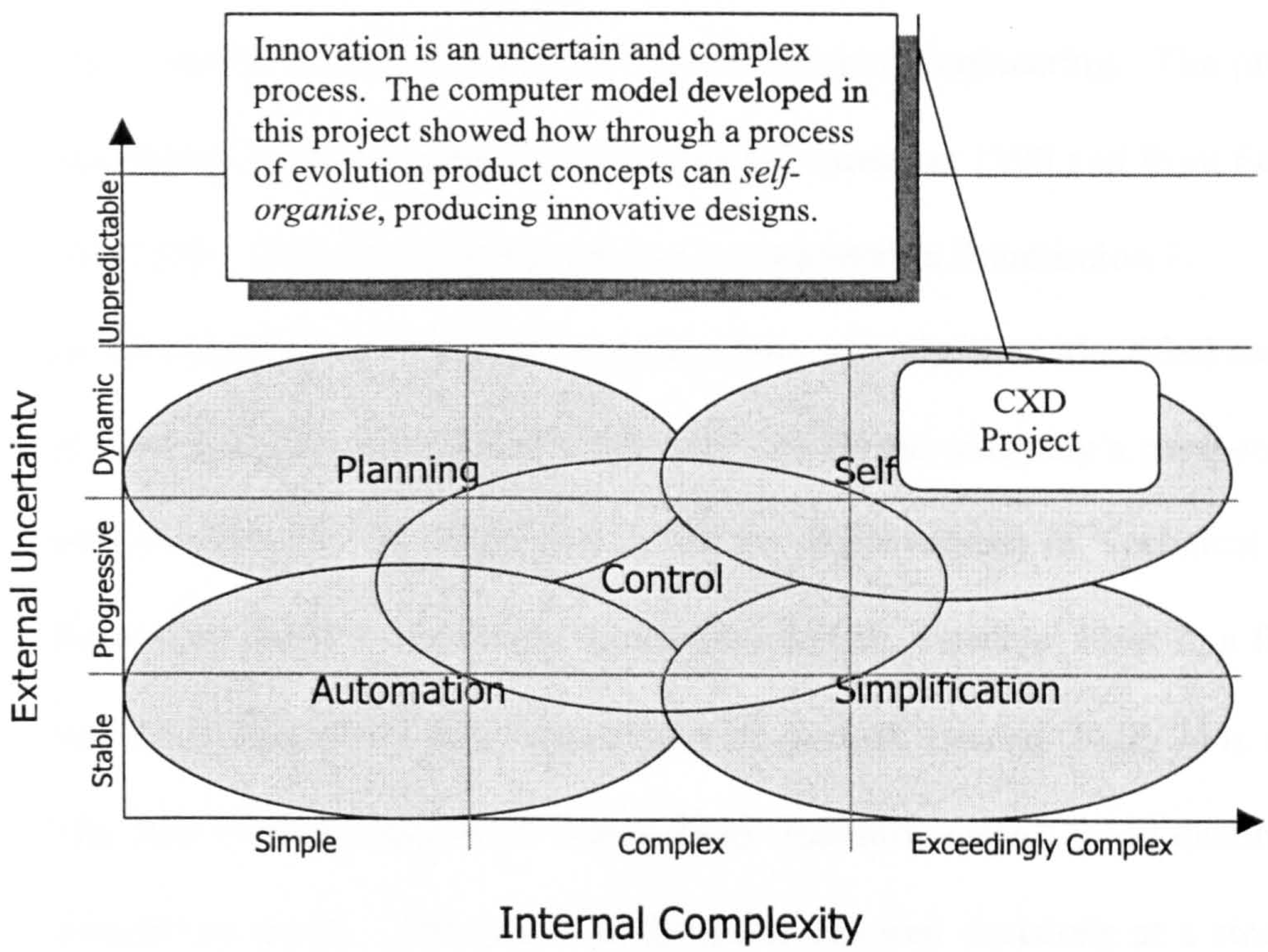
5.3.2 Contributions to the Research

The HS Marston case study provided a new dimension to the model by presenting the need for organisations to learn and innovate. Learning and innovation are highly complex processes required to cope with highly uncertain situations. The strategies found in the other case studies focused mainly on control, simplification and automation, which were not sufficient to deal with this situation. This emphasised the need for strategies that are capable of dealing with this level of complexity and uncertainty and provided the first real indication that the concepts of Complexity Theory could form part of the model.

Developing new products require organisations to make relatively large investments, before it is known whether the product will be successful. This uncertainty is even greater in the case of suppliers in the aerospace industry, because bids are either accepted or rejected. If a bid is accepted the company will ensure a long-term contract and recover the investment, however, if the bid is not accepted there will be no economic reward for the efforts and investment put into developing the product. However, the most important element in uncertainty, is the fact that every product development project is unique and that the results are unknown to a certain degree. That is, they are known in terms of the performance outcomes and certain characteristics, but they are unknown in terms of their internal structure, materials and configuration. Predicting the configuration of the outcomes of the bid is beyond any forecasting technique, so for this reason the project has been classified as *dynamic* on the uncertainty scale. To turn to Complexity as encountered at HS Marston, relatively small teams formed by designers, manufacturing engineers and salesmen work together in developing heat exchangers. Developing a product can take up to two years requiring constant interaction, not only among the members of the development team but also with the potential customer, in order to review progress and specifications. Generally, the requirements in this industry are continually challenging established boundaries of performance, forcing the knowledge and expertise of the team to its limits. Throughout the development process, different ideas and concepts are introduced, modified, combined and selected before developing the final product. However, even when the product specifications are relatively stable, complex creative processes are necessary to arrive at the final product. In these creative processes, strong interdependencies exist and it is impossible to break them down and describe them in detail, not to mention predict their behaviour. For these reasons this case study was classified in the *exceedingly complex* category.

Figure 28 positions this project and the conclusions and recommendations produced in the Complexity –Uncertainty model.

Figure 28: Generic Strategies Analysis - CXD Project



The research explored the application of the analogy of evolution to the new product development process, through the use of a genetic algorithm (GA). In this exploration it was found that important aspects of evolution, such as mutation, crossover and selection had equivalents in the product development process. This evolutionary view of product development can help to shift the traditional focus of a centrally controlled process that can be perfectly planned, to a self-organising process where people are continually interacting and shaping the final product, without knowing exactly what the final product will be like.

This innovative approach to looking at new product development emphasises the importance of diversity, learning and collaboration in the development process. Furthermore, this case study was the first to show the limits of planning and control, and revealed the potential of self-organisation as a strategy for dealing with highly uncertain and complex situations.

5.4 Aircraft Maintenance Project

This research was conducted for British Airways Engineering. The project was undertaken in two periods from October to December 1999 and from February to May 2001. The report for this project is presented in Submission 7.

At this stage, the five generic strategies have already been identified and the role of this case study was one of validation. From the company's perspective there was an objective of identifying areas for improvement in Technical Dispatch Reliability (TDR). The study focused on British Airways' Fleet 2, a fleet of 81 aircraft composed of three main types of aircraft, Boeing 742s, 744s and 777s. The fleet operates long-haul flights from Heathrow airport to 40 destinations all around the world. The scope of the study covered decisions at a strategic and tactical level, but not at an operational level.

Two different approaches were used, the first was to analyse historical data to identify and understand patterns, and to test for correlations between TDR and other variables. The second approach was to develop a simulation based on an original algorithm used by BA. This original model was modified to enable the prediction of TDR for Fleet 2. The "Technical Dispatch Reliability Model" (TDRM) uses schedule data, fleet data and other historical data to estimate different operational variables such as delays, cancellations and TDR.

5.4.1 Contributions to the Organisation

Punctuality is a significant element in customer satisfaction and loyalty. TDR is not a complete measure of punctuality, as it only considers the impact of engineering and maintenance activities on punctuality. However TDR is important in focusing maintenance efforts to deliver aircraft in proper operating conditions and on time for flights.

The statistical analysis revealed a number of findings about TDR that can affect decision-making and help to improve performance. The following list summarizes these findings:

- Average TDR performance for Fleet 2 from 1999 to 2001 was below the target of 94 %. Only the 777 fleet achieved above target performance but 742s were considerably below target with 87.7 %
- Statistical evidence showed that TDR performance has been deteriorating over the past three years. This deterioration can be attributed mainly to the 742 segment of the fleet.
- Despite the widespread belief within British Airways that "acceptable deferred defects" (ADDs) have an impact on TDR, no statistical evidence of this impact was found in the research.
- An analysis of the age of the fleet showed that older aircraft tend to have lower TDR performance.

These findings provided the organisation with a better understanding of their performance in terms of TDR and helped them to identify the elements that affect it. However, it was the development of the Technical Dispatch Reliability Model (TDRM), which provided them with a tool that will allow them to take action to improve the performance of this measure.

The TDRM can be used to compare the impact of different potential schedules on TDR performance and to determine TDR targets by aircraft type, for future seasons. Tests performed during the project showed that TDRM is able to forecast TDR performance of a particular schedule with a +/- 2 percent accuracy. The TDRM model can be used in BA's planning and scheduling process, and will help in developing schedules that do not adversely affect TDR performance. Unfortunately, the model also has its limitations. The following table shows the main benefits and limitations of the model.

Table 19. Benefits and Limitations of TDRM

Benefits	Limitations
• The model is able to forecast TDR performance for the entire fleet, segmenting the data by aircraft type • It allows the impact of different schedules on TDR to be compared • The model also gives an indication of other variables such as delays, cancellations and substitutions. • It allows the impact of changes in the fleet to be analysed. • Tests of the model have demonstrated a high reliability. • The model can be used as an aid to the planning and scheduling process	• The system has heavy data requirements. Most of this data has been collected, and could be used for future seasons if no major changes to the fleet or the operation are implemented. • Adapting the system for future changes in the fleet requires some understanding of the Witness software package • Preparing the input data and putting it in the right format is a cumbersome process. • Data concerning delays and casualty distribution have to be regularly updated for the system to maintain its accuracy. • Major changes to the maintenance operation would affect the reliability of the simulation.

The model can help British Airways to analyse and compare schedules and select those that minimise the impact of uncertainty in the punctuality of flights.

5.4.2 Contributions to the Research

British Airways participates in a global market, and is affected by many different environmental factors, such as economic and social conditions, technological evolution and weather conditions. An extreme example of these influences is the effect that the events on September 11th 2001 have had in the entire industry: slowing down demand; putting pressure on security issues; reducing investor confidence and causing deterioration in the overall financial situation of most companies in the industry. Apart from such events, the nature of change in the industry is not all completely unexpected, and it is possible to identify some general patterns and trends. Similarly, it is possible to identify patterns and trends in maintenance requirements for aircraft, using statistical analysis and making forecasting relatively accurate within the short and medium term. Hence, this case has been classified as *progressive* on the uncertainty scale.

British Airways offers a large number of flights with a vast network of destinations, handling more international passengers than any other airline. It is estimated that a flight departs, on average, every 30 seconds worldwide (British Airways, 2001). Internally, the company has to deal with many different variables and constraints such as crews, aircraft, airport facilities, landing and takeoff slots, catering services, and the large international operation requires the ability to work in many different cultures and languages, and to deal with several regulatory bodies in different countries. The intricate structures of the company and the rich interconnections and interdependencies that exist have led to the classification of this case as *complex*.

In dealing with uncertainty and complexity, BA uses a whole range of strategies. *Planning* was identified as a key process that takes place at several stages and for different lengths of time, from network development, which looks 10 years into the future, to operations control, which looks at the next 2 or 3 days. *Control* is another strategy that is particularly used in the industry, both because of the regulations imposed by national and international aviation authorities, and because of BA's internal controls. *Automation* is employed to manage certain repetitive tasks, and to transmit information between different sites, which is particularly important in a global organisation.

This project focused on the small part of the overall airline operation which refers to the maintenance efforts to provide safe aircraft on time, as measured by

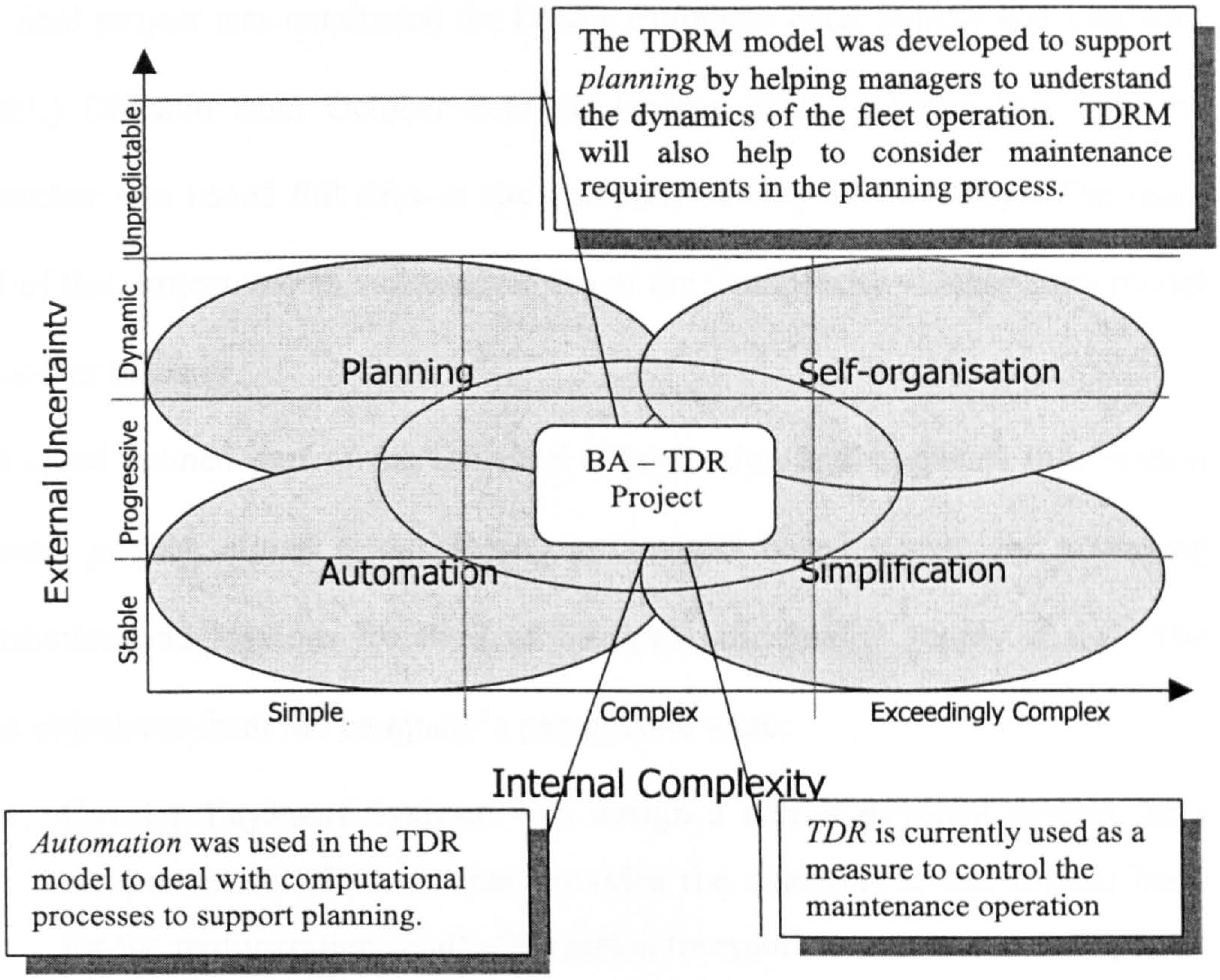
TDR. The TDRM model supports a *planning* strategy that can be used to develop schedules that improve TDR performance and can help to identify better ways to assign and organise resources to cope with uncertainty in the environment, minimising its impact on the operation.

The TDRM also uses an *automation* strategy to simulate the operation. The model uses the Discrete Event Simulation (DES) technique which could be useful for dealing with certain aspects of complexity and uncertainty, as is explained here:

- Uncertainty: The model incorporates variability into a simulation by using statistical distributions which make the system more realistic and which help to assess the impact of deviations in the process. Distributions of aircraft flying times, repair times, casualty probabilities, and the length and probability of delays were used in the simulation. These distributions however have been calculated based on historical information and hence they would not take in unexpected events.
- Complexity: In simple systems cause-effect relationships are generally close in space and time and there is no need for sophisticated tools to understand the impact of decisions or actions in the system. By contrast, complex systems tend to hide causal relationships due to the interaction of different elements and the delays in the system. The model has been used to understand the complex dynamics of the operation, identifying the interaction of different factors and assessing the impact on TDR and other measures.

Figure 29 shows the main generic strategies used in this project mapped in the Complexity – Uncertainty model.

Figure 29: Generic Strategy Analysis – TDR Project



This case study served as validation for the Complexity-Uncertainty model. It provided evidence of three of the generic strategies, automation, planning and control. This case study also helped to highlight the limitations of these strategies in "controlling" uncertainty, making evident the need for self-organising approaches that can cope with uncertainty without central control. The position of this case in the model seems to suggest that self-organisation and simplification could also be used as strategies, indicating opportunities that the organisation might be missing.

At this stage it became evident that the model could play a role in educating managers about the alternatives for dealing with complex and uncertain situations.

5.5 DEALIS Project

The final project was conducted for Ford's European Parts Supply and Logistics (PS&L) Division from October 2000 to January 2001. During this time the researcher was based full time at the company facility in Daventry. The main goal of this project was to validate the use of the Complexity –Uncertainty model in another industry.

This cased formed part of the DEALIS (Distribution and Logistics Information System) project, aimed at developing an Internet based system for managing distribution and logistics for Ford of Europe's aftermarket supply chain. The main objectives from the company's perspective were:

1. **Carrier Payment System:** To design a carrier payment system, as a component of DEALIS, that provides the quantitative and logical basis for the remuneration of all aftermarket transport contractors in Europe.
2. **Outbound Shipment Reporting System:** To design a reporting system for outbound shipments within DEALIS, that could support local and global decision-making.
3. **Supply Network Strategies:** To analyse Ford's strategies for managing complexity and uncertainty in their aftermarket supply network, in particular those strategies related to the development of DEALIS.

A number of approaches and tools were used to achieve these objectives. Semi-structured interviews were conducted with personnel in the traffic, logistics and systems planning departments, at the three main distribution centres in Daventry (UK), Valencia (Spain) and Cologne (Germany) to understand the processes and system requirements. An assessment form was sent to all the traffic managers to determine their information requirements. Information regarding payment methods for all the different routes around Europe was collected through telephone contact and e-mail.

Flow Diagrams, and Entity Relationship Diagrams were used to understand and analyse the current processes and to describe future processes after the implementation of the system. These tools were also useful for communicating the results of the project and for developing the computer system.

5.5.1 Contributions to the Organisation

The two main deliverables for the organisation were the design of the Outbound Shipments Reporting System and the Carrier Payment System. The report presented to Ford included the steps required to develop these two systems as well as some other areas of opportunity identified during the analysis. A description of the two systems and the benefits that Ford will obtain after their implementation are presented here:

a) Outbound Shipments Reporting System (OSRS)

The OSRS was designed to be a component of DEALIS which could provide statistical and historical shipment data, allowing traffic managers to consolidate, filter and compare this data, and helping them to monitor and analyse the operation. The data managed by this system is mainly related to volumes (shipments, lines and weights) and carrier payment details, as required by Ford. Further developments to the system were suggested in order to expand its functionality for providing other types of reports, such as costing, customer satisfaction and efficiency.

b) Carrier Payment System (CPS)

The Carrier Payment System was designed to allow cost reporting and carrier payment. The current carrier payment process is completely manual and relies on a number of reports to authorise carriers' invoices. The CPS will manage tariffs and rates data for all routes currently operated, calculate freight charges, and generate cost reports, automating the entire process, reducing costs and eliminating mistakes.

5.5.2 Contributions to the Research

The automotive industry presents a dynamic environment affected by various factors such as the global economy, oil prices, the competitors' behaviour, the customers' changing needs, technology development and environmental issues. However, the market for spare parts (aftermarket) is more predictable than the one for new vehicles, because there are figures about the number of vehicles on the road, their age and distribution, making it possible to forecast the demand for components. This forecasting capability diminishes over time as vehicles change location and are substituted by new vehicles. For these reasons this case has been classified as *progressive* in the uncertainty scale.

The Parts Supply and Logistics Division (PS&L) is responsible for distributing aftermarket components and providing services to all Ford dealers in Europe. The system operates from three source depots in Cologne (Germany), Valencia (Spain) and Daventry (UK) and four Parts depots in Portugal, Italy, France and Sweden. Every day over 160,000 lines of product are dispatched from the three main distribution centres. The operation is supported by more than 50 external carriers that distribute the parts, operating over 100 regular routes, and serving thousands of dealers and millions of customers. The system presents a large network of closely interrelated stakeholders such as dealers, source depots, part depots and carriers, as well as regional and European traffic and logistics offices. However, this large and highly interconnected network can still be broken down and described in terms of its individual components, for this reason it has been classified as *complex* on the complexity scale.

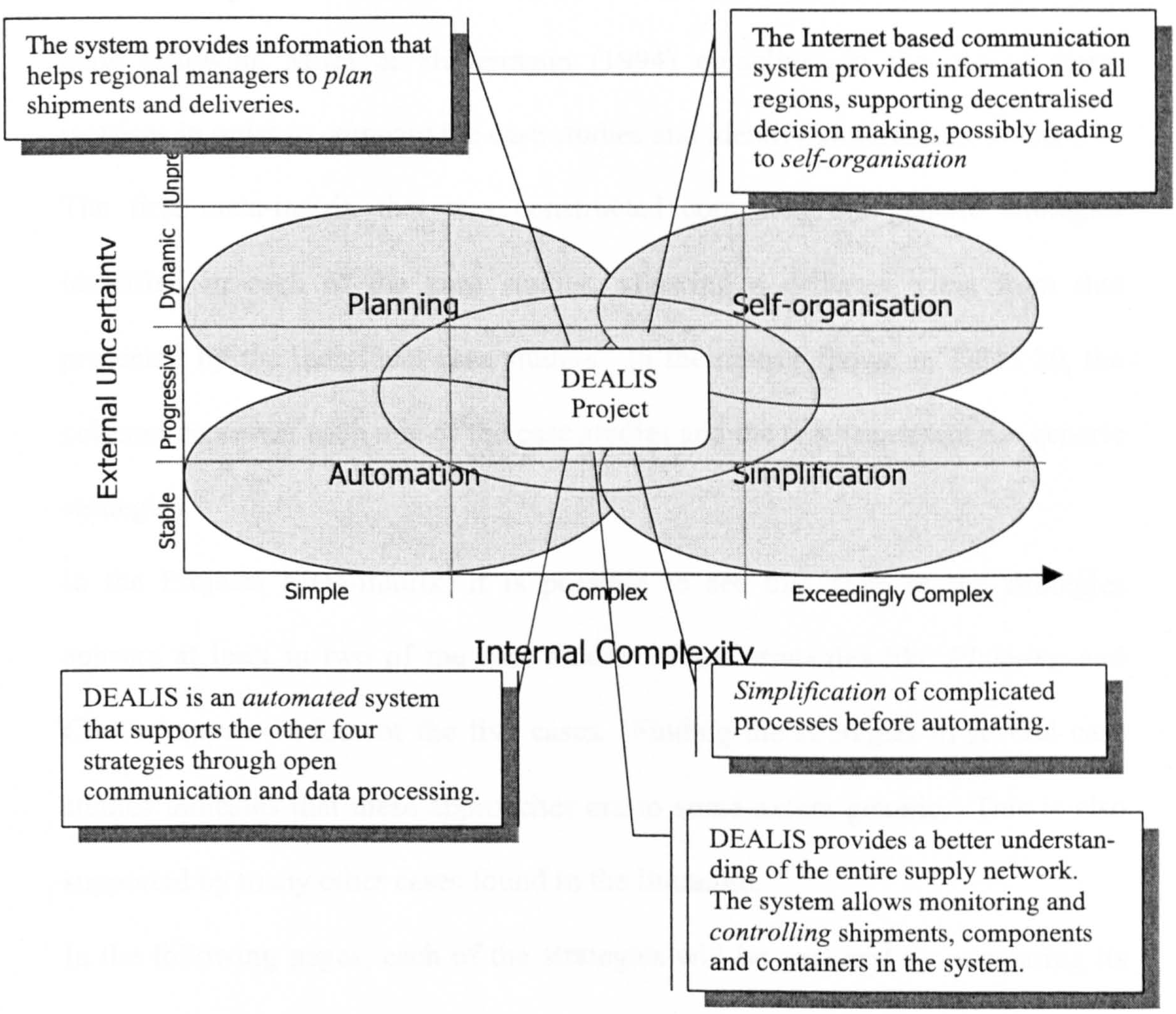
In Ford European Distribution operation regional departments, carriers and suppliers have been empowered to make decisions such as the routes that will be used, the carriers that will operate them, and the levels of stock that will be held at every location. This decentralised approach allows the network to be more flexible and to respond effectively to regional issues. However, it can lead to errors and inefficiencies, if the information is not shared among all the different members of the network.

DEALIS has been developed with several objectives in mind, such as allowing transparency and information sharing along the supply network, as well as streamlining the system by eliminating or modifying inefficient processes. All of these objectives are approaches to dealing with complexity and uncertainty in the supply system. Computer systems can manage calculations and arrange information in different ways, much more efficiently than people. This opens opportunities for *automation* of certain tasks as described for the Carrier Payment System. DEALIS also provides a mechanism for *controlling* the operation, a primary role of the Outbound Shipments Reporting System.

DEALIS allows the free flow of information, making the entire supply system more transparent, and providing regional managers with complete information to *plan* and make decisions for the future. Better interaction between all the members of the supply system – Ford's internal departments, carriers, suppliers, and dealers – creates interdependencies between them, allowing *self-organisation* to take place. This closely interlinked system also allows a greater diversity of possible reactions increasing the complexity of the entire supply system, and enhances its ability to cope with uncertainties in the environment.

The case study with Ford has provided an example of how a multinational organisation deals with complexity and uncertainty in its supply network. In particular, the development of DEALIS has helped to exemplify how different strategies such as automation, simplification, planning, control, and self-organisation can be used to manage a supply network. These different strategies show how both simplicity, to gain efficiency, and complexity, to develop flexibility and innovation, can co-exist as part of a supply network strategy. The five strategies used in the DEALIS project are shown in Figure 30.

Figure 30: Generic Strategy Analysis – DEALIS Project



The final case study with Ford provided examples of the application of all of the generic strategies and confirmed the use of the strategies in a different industry. This supports the argument that the strategies are not exclusive to the aerospace / aviation industry and that the model can be applicable to other industries.

At this stage in the process the model had already been fully developed and it was possible to present it to the managers involved in the case-study project. The managers stated that they found the model useful for clarifying the alternatives available to manage complexity.

5.6 Cross-Case Analysis

This section presents a cross-case analysis of the case-studies. This analysis was done following Miles & Hubermann (1994) guidelines in the use of meta-matrices in order to compare the case studies and identify patterns across them.

The first meta-matrix that was constructed compared the generic strategies identified in each of the case studies, allowing a different view from that presented by the individual case studies. In the matrix shown in Table 20, the columns represent each one of the case studies and the rows represent the generic strategies.

In the Projects Meta-matrix, it is possible to see that each of the strategies appears at least in two of the case studies. Some strategies like *Planning* and *Control* appear in four of the five cases. Finding the strategies in several case studies indicates that these approaches are to some extent generic. This is also supported by many other cases found in the literature.

In the following pages, each of the strategies will be analysed by comparing its use in each of the case studies. This will help to find patterns and commonalities across case studies.

Table 20: Projects Meta-matrix

	British Midland Performance Measurement	**British Airways** Component Repair	**HS Marston** CXD	**British Airways** Technical Dispatch Reliability	**Ford** DEALIS
Automation	Automation of repetitive activities (i.e. calculations)			TDRM is an automated model	DEALIS automates functions within the organisation
Simplification		Simplification used to eliminate elements of unnecessary complexity			Certain processes were simplified before automation
Control	Performance measures allow more control of the operation	Control through performance measures (e.g. TDR and WIP)		Technical Dispatch Reliability is a measure of control	DEALIS allows monitoring and control of shipments, components and containers
Planning	Performance measures help to plan for the future	Improved planning through better understanding of future workload.		TDRM was developed to support planning activities.	DEALIS aids planning of shipments and deliveries
Self-organisation		Increasing diversity and redundancy of skills could promote self -organisation	Model shows how the evolution of product concepts through self-organisation		Decentralisation and open communication can promote self-organisation

a) Automation

The Automation strategy was found in three projects, British Midland Performance Measurement, British Airways - TDR and Ford DEALIS. These three case studies involved the development of computer systems which would automate certain functions within the organisation, replacing processes that were done manually or that were not done at all.

In the case of British Midlands, automation consisted of the creation of a system that would automatically collect data and calculate certain indicators. In the Ford DEALIS project, automation was used to substitute manual activities, mainly calculations and comparisons, for the validation of invoices. In these two cases, automation provided process improvements through efficiency and elimination of mistakes. This was possible because the functions automated were part of standard processes and did not require a high degree of adaptability or flexibility: they required reliability and efficiency.

In the British Airways – TDR project, automation was the main strategy since the Technical Dispatch Reliability Model (TDRM) is an automated model that performs a large number of calculations to estimate the operation of the fleet. These was different from the other two case studies because it did not replace an activity that was currently being performed, it created a new activity. The calculations performed by the TDRM could, in theory, be performed manually, although this would be a labour intensive task. As in the other two cases the TDRM would not be effective in a changing environment, since the calculations would tend to lose reliability quickly and the system would be outdated very soon. This helps to support the argument that Automation is located in the low uncertainty region of the model.

Automation was possible in these three cases because the processes being automated were clearly understood and could be broken down into their individual activities. This detailed examination of the process is what makes automation possible. On the other hand, intending to automate complex systems, where problems cannot be clearly defined and relationships are not understood, would not be feasible. This supports the decision to locate the automation strategy in the low complexity region.

b) Simplification

The simplification strategy was identified in two of the case studies, British Airways Component Repair and Ford - DEALIS. In the Component Repair project with British Airways, it was found that the process was very fragmented and that some of the activities and changes of ownership were not required for the repair. In many cases the process did not require the level of complexity that they had been designed for, in fact, these complexity would only slow down the process, without bringing any benefits to the company.

In the Ford - DEALIS case, Simplification was suggested to reduce the variety of Carrier Payment methods. It was found that different subsidiaries in different counties used a variety of payment methods for carriers. This diversity of methods did not have any benefits for Ford or for the carriers and it did create difficulties in calculating payments and comparing performance between regions. In both case studies, Simplification was used to reduce complexity within the system in situations where this complexity was not required by uncertainty in the environment. This supports the decision to locate this generic strategy at the high complexity low uncertainty end.

c) Control

Four of the case studies revealed the use of the Control strategy, the only exception was the CXD project. This does not mean that control is not or should not be used in this project. It means that control was not the considered to be an appropriate strategy considering the scope of the project, which focused on product innovation.

Three of the projects where the Control strategy was identified were related to the measurement of performance (i.e. BM - Performance Measurement, BA – Component Repair and BA – TDR).

Performance Measurement was the central focus of the case study with British Midlands. In this case, a comprehensive system for measuring performance was developed, covering financial, operational, service and continuous improvement measures. The main reason for having these measures was that, it is in the interest of the company to keep these factors within certain limits. Measurement is an essential element in the feedback and control process and in this case it was required for monitoring the operation and maintaining performance within specified limits. In the two case studies with British Airways, performance measurement played a similar monitoring and controlling role, although in these cases measuring performance was not at the centre of the study.

In the DEALIS project control went beyond measuring performance. DEALIS helps to monitor the traffic operation for Ford of Europe, highlighting any deviations and prompting managers to make decisions to maintain the system under control. In this case, the computer system would take a larger role in the negative feedback loop, by measuring performance, comparing this measurement to a predetermined standard and prompting for action.

Measuring performance and comparing it to standards are only parts of the feedback – control loop, which does not necessarily imply that control is being maintained. In order to complete the loop, an action that modifies the inputs to the system is required. In relatively simple systems, the impact that actions will have on the variable being measured can be known, however as complexity in the system increases, the degree to which this variable can be controlled is reduced. In a system that is intended to create innovation, as in the case of the CXD project, it is much more difficult to know which actions to take and what impact they will have on the system.

d) Planning

Planning was found in four of the projects and the only exception was the CXD project. Similar to the control strategy, the fact that planning was not considered in this project does not mean that HS Marston does not require planning, but that planning would not have major benefits for the particular situation under study.

In the BA Component Repair project, the Machining and Process Centre (MPC) did not have any visibility of future workload, making the planning of manpower and equipment practically impossible. Suggestions were made to improve visibility, by using information of the components under repair in the work centres that fed the MPC. Even when this suggestion only gave a few weeks visibility and was not one hundred percent accurate, it gave the possibility of planning the workload and freeing resources accordingly. The DEALIS project presented a similar case, in which the system could give visibility of incoming shipments and deliveries, allowing better planning of warehousing operations.

The TDR project with British Airways, presented a different aid to planning through simulation. Here the model helped decision maker to gain understanding about the operation of the system, particularly about how maintenance requirements would be affected by different schedules. This in turn helped the selection and modification of future schedules that were realistic for the maintenance operation. The model however, was limited in terms of the period in which it could produce reliable results and in the degree to which it can could with unexpected events, like September 11th. This is one of the limitations of the planning strategy to cope with highly uncertain circumstances.

e) Self-organisation

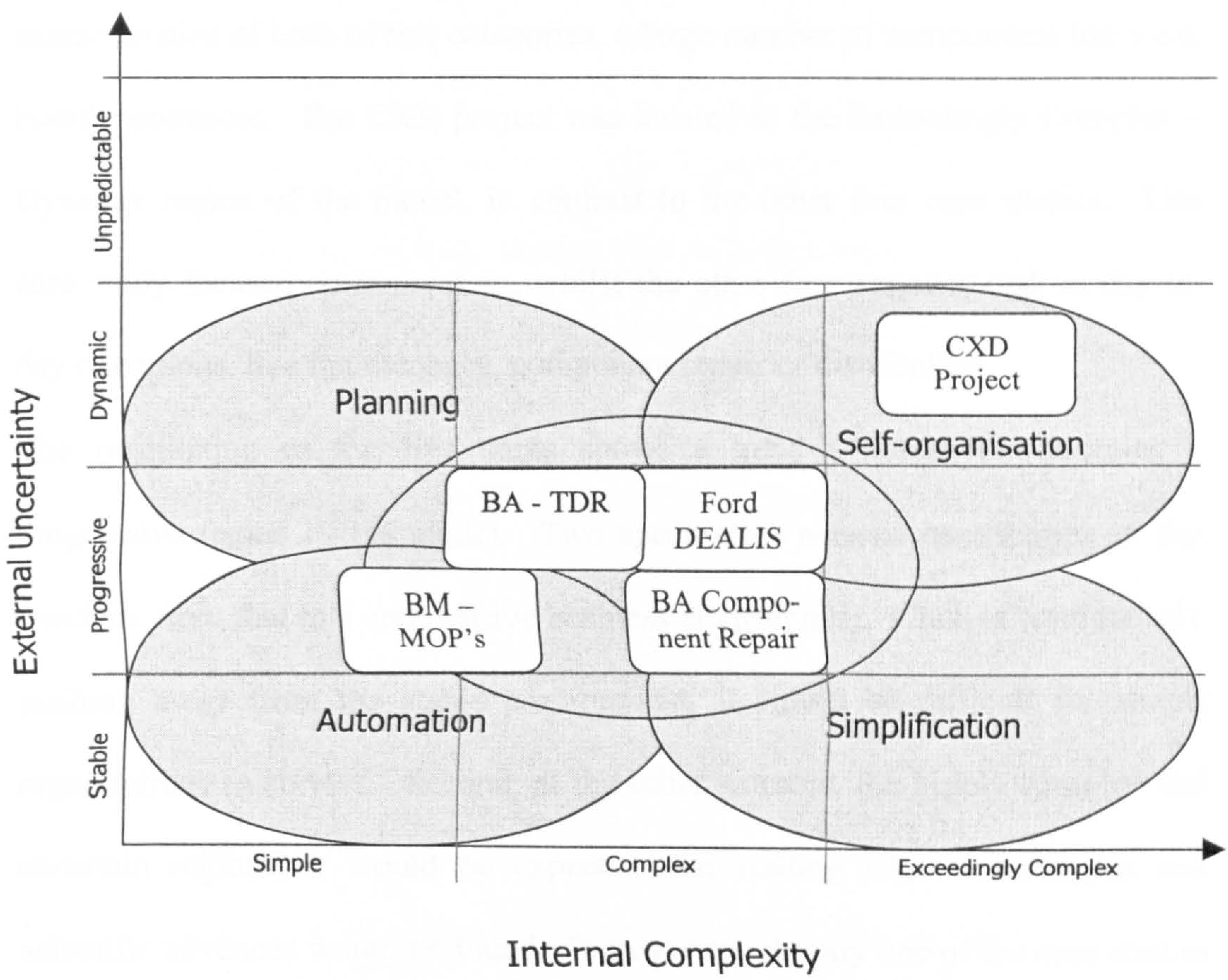
Potentially, self-organisation could have appeared in any of the case studies, since it was not an intended outcome of management actions but a process that resulted from the interaction of the elements in the system. However, it was found in one of the cases and in another two it was identified as a possible development. In these three cases the other four strategies were insufficient for dealing with the levels of complexity and uncertainty. These cases were CXD, Ford - DEALS and BA Component Repair. In these cases, it is suggested that self-organisation could play a role in creating new forms of order within the organisation, making it more adaptable and responsive to the environment.

In the CXD project, self-organisation appeared as an essential process in the evolution of product concepts. Here it is suggested that self-organisation allows different product concepts to be combined, mutated and selected in the process of reaching a final product design.

In both DEALIS and BA's Component Repair project, suggestions were made concerning the possibility of self-organisation taking place with the potential of benefiting the organisation. This required actions that would create situations that fostered self-organisation, such as decentralising control, improving information flows, and allowing political and learning processes to take place within these two organisations. In these cases complexity in the system was required to allow self-organisation to take place, however these systems were also capable of coping with higher degrees of uncertainty.

The grid structure of the Complexity – Uncertainty Model allowed it to be used as a meta-matrix, where different situations can be positioned and compared. Using the model, the five case studies were compared in Figure 31.

Figure 31. Cross Case Analysis



Key:
BM – MOP's = British Midland Measures of Performance Project
BA – TDR = British Airways Technical Dispatch Reliability Project
Ford DEALIS = Ford DEALIS Project
BA Component Repair = British Airways Component Repair Project
CXD Project = Complexity in Product Definition Project

Three of the cases were found in the Complex - Progressive region of the grid. These cases were found to be complex because they were constituted from a relatively large number of entities and showed some degree of interdependence. Similarly in the three cases it was possible to identify certain patterns in the environment and forecasting, although limited in time and accuracy, was still possible. The British Midlands project on Performance Measurement was also found in the progressive region; however, in the complexity scale this project was positioned between the simple and complex regions because it presented characteristics of both of this categories, a large number of components but weak interdependences. The CXD project was located in the Exceedingly Complex – Dynamic region of the model, in contrast to the other four case studies. This case study focused on innovation, whilst the other four concentrated on day-to-day operations, like maintenance, component repair or distribution.

The positioning of the five cases shows a trend towards the Complex – Progressive region of the model. Two speculative reasons contributing to this trend are first, that in a competitive business environment, which is continuously pushing away from the stable environment, it would be difficult for simple organisations to survive. Second, at the other extreme, the highly complex and uncertain regions, it would be expected that leading edge technologies and scientific advances would be found. In this research only one of the case studies showed these characteristics. This points to another possible reason for the central trend, which is the selection of the case studies. However, before the cases were selected the model that would emerge was unknown and it was not intended to select cases in any particular region. Further research could concentrate on specific regions of the model.

6 Conclusions

The early stages of this research were influenced by two factors, the identification of the need for a set of guidelines on how to deal with complexity in organisations, and also the development of Complexity Theory as a potential contributor to the creation of these guidelines.

The experience gained during the case studies helped to reinforce the need for a model that could help managers to deal with complexity. In traditional management literature, complexity is often portrayed as an undesirable but necessary characteristic of organisations. Consequently, most of the proposed solutions focus on simplification – the elimination of all "unnecessary" complexity. However, defining exactly what is "unnecessary" complexity is not straightforward, as the environment is continually changing, and what might be unnecessary in the current environment, might be essential in the future. Furthermore, a system in which complexity is continually reduced loses the variety and flexibility required to experiment in future situations, leaving no room for change.

The other important factor that influenced the early stages of the project was the emergence and development of Complexity Theory. The theory presented a new view in which complexity is considered an essential element for the evolution and sustainability of systems. The existence of different schools of thought about complexity, each one with a different understanding of complexity in organisations, was a challenge of the research. The result has been a synthesis of the different views in which some of the concepts of Complexity Theory and the more traditional views about complexity are joined into a single framework.

The project adopted three main objectives. In order to evaluate the results of the research, each of these objectives will be evaluated. The first objective was to identify from the literature the concepts and applications of Complexity Theory that were relevant for the collaborating companies. This objective was accomplished mainly in Submission 1 –which presents the main concepts of Complexity Theory– and Submission 2 –which concentrates on the possible applications of these concepts in organisations. This submission has presented a summary of the main concepts that were useful for this research and the literature review section has been updated and expanded.

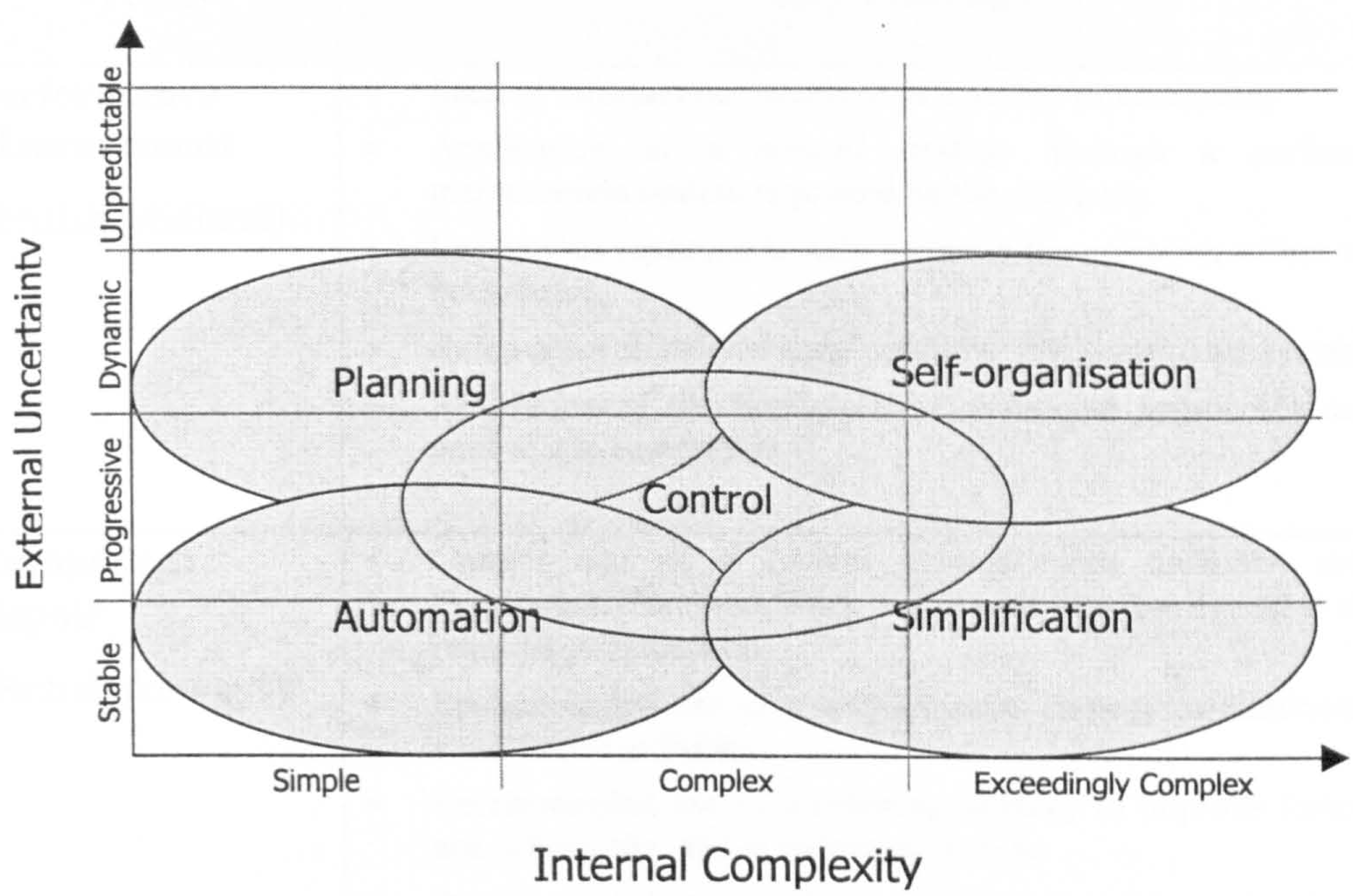
The second objective involved analysing the strategies followed by the collaborating companies to manage complexity, and to assess the applicability of the concepts of Complexity Theory. This process took place during the case studies where the different approaches used by the companies to deal with complexity and uncertainty were analysed and documented, supporting the accomplishment of this objective.

The final objective of the project was to create a model that would help to understand complexity in organisations, which was the main innovation of the research. The process of creating the model started by linking two variables, internal complexity and external uncertainty. The identification of these two variables was influenced by two theoretical concepts. The first one was a framework developed by Wienberg (1975) which relates Complexity and randomness, and identifies three different regions with certain characteristics. The other concept was Ashby's *Law of Requisite Variety* (Ashby, 1956), which states that the variety of outcomes of a system in response to its environment, can only be decreased by an increase in the internal variety of the system.

The first of the research questions intended to explore how managers dealt with situations of complexity and uncertainty. Based on the case studies it was possible to start categorising the five generic strategies: Automation, Simplification, Planning, Control and Self-organisation. The last of these approaches, Self-organisation, was central to dealing with the second research question, which referred to how companies could benefit from the concepts of Complexity Theory. The research helped to show that Self-organisation is not only a concept that has potential benefits for organisation, but also one that is essential for supporting organisations operating in uncertain and complex situations.

The process of answering the two research questions resulted in the development of the model shown in Figure 32.

Figure 32: Complexity - Uncertainty Model



The model is descriptive and helps to uncover certain aspects of the structure and behaviour of organisations. This will allow people to understand and learn about their organisations and the environment around them, ultimately leading to better decision-making.

The definition of the five categories had a theoretical background from previous classifications by Handfield (1995) and Gregory and Rawling (1997) and from the literature on the application of the concept of Self-organisation in social systems (Stacey, 1993; Kauffman, 1995a). However, the main input for the development of the classification was the results obtained from five case studies. Each of the cases made its own contribution to the development of the model. The following table shows the contributions of each of the projects.

Table 21: Contributions of Industrial Projects to the Research

Project	Key Findings
Performance Measurement (British Midland)	• Lack of information perceived as a source of uncertainty • Application of a *control* strategy through a performance measurement system requested by the company. • Continuous reporting to help maintain the operation within certain boundaries. • *Automation* applied to some repetitive functions of the system. • Realisation of the limitations of traditional approaches such as control and automation
Component Repair (British Airways)	• Current use of a *control* strategy with measures such as Turnaround Time and Work in Progress was insufficient to deliver required performance. • Recommended use of a *simplification* strategy to eliminate non-value added activities • Recommended use of a *planning* strategy to improve forecasting and scheduling, and to reduce cycle time • Recommended cross-training to increase variety and redundancy opening possibilities for *self-organisation* • Identification in the literature of two methods for classifying strategies for dealing with complexity

Project	Key Findings
Product Design (HS Marston)	• Identified similarities between the product development processes and evolutionary processes • Identified the importance of diversity of ideas for innovation and self-organisation • Identified importance of learning and collaboration for *self-organisation*
Aircraft Maintenance (British Airways)	• Current use of TDR as a *control* measure, but without a link to planning. The planning process only considers some related measures • The use of the TDRM model to consider TDR during the *planning* process • *Automation* of the analysis process through the development of TDRM • Discrete event simulation (DES) tested as a tool for understanding complexity and uncertainty. • Contributed to validation of the research
Supply Systems (Ford)	• Development of DEALIS to allow communication and decentralisation of control, possibly motivating *self-organisation.* • DEALIS as a tool that supports *planning* and *control* • DEALIS is essentially an *automated* system • Contributed to validation of the research

The case studies helped to map the five strategies in different regions of the complexity-uncertainty grid. However, the unpredictable region of the grid remained unpopulated because none of the case studies was located in this region and therefore there was no empirical evidence to support conclusions in this region of the model. In the available literature there is some evidence that self-organisation might also prevail in this unpredictable region, however it was not possible to validate this in the research.

The case studies also provided immediate contributions to the organisations, involving innovative findings and developments. Table 22 summarises some of the main contributions to the organisations.

Table 22: Contributions of Industrial Project to the Organisations

Project	Contribution to the Organisation
Performance Measurement (British Midland)	• A new performance measurement system was developed and implemented, allowing the management team to have a better understanding of the organisation, enabling them to monitor and control performance. • The analysis of the operation also helped to identify other areas of improvement such as the excessive workload in the Commercial department. Recommendations were made to deal with these issues.
Component Repair (British Airways)	• The following areas of opportunity were identified: process cycle time, planning & scheduling people issues, management of bottleneck resources, use of performance measurement and the use of sub-contracting. • Specific actions were recommended to address each of the areas of opportunity.
Product Design (HS Marston)	• The research presented a new way of thinking about product development in the organisation • Diversity of designs was identified as important in achieving innovation. • The need for developing, managing and retaining knowledge within the organisation was identified as a very important issue for successful product development.
Aircraft Maintenance (British Airways)	• Statistical evidence of the deterioration of TDR was found, and some of the factors leading to this deterioration were identified. • The development of the TDRM model will help the organisation to develop schedules that support TDR performance.
Supply Systems (Ford)	• The development of the Carrier Payment System and the Outbound Shipment Reporting System will help to increase the capability of DEALIS as a System for supply chain management

Models are abstractions that represent certain aspects of reality that are considered important or relevant for analysis. For this reason, there are many different types of models that have different objectives and consider different variables. The model that has been developed in this research considers complexity and uncertainty as the main variables, since they reflect important aspects of reality and can be useful for understanding organisations and guiding decision-making.

The case studies have shown that the Complexity-Uncertainty Model can help to understand an organisation's internal complexity in relation to the uncertainty in the environment. This in turn supports the development of strategies to create an organisation that is flexible in dealing uncertain situations, but not too complex that it becomes inefficient and unpredictable. This is a step towards improving the competitive position of an organisation.

The Complexity-Uncertainty model challenges the idea that complexity is a necessary evil in organisations and highlights the advantages of complexity in dealing with an uncertain environment. On the other hand, the model acknowledges that organisations can become too complex for people to manage. The model does not make a value judgement about complexity, and accepts its benefits and limitations for an organisation, providing a framework of alternatives that managers can use in different situations. Hence, it can be used as an educational tool to help managers conceptualise the nature of complexity and the range of options that are available.

7 Further Research

This research has helped to develop the understanding of complexity in organisations by providing a framework to which organisations can relate and within which they can take action. However, this is only a small element of an ongoing process of understanding organisations and the people within them, and how they behave in an uncertain environment and complex situations. This section presents a number of different areas for further research.

a) Organisational Performance

In the research, elements have been found which relate the five generic strategies to different situations, and arguments have been presented about how these strategies could help in a particular situation. However, it was difficult to assess the precise impact of each strategy on organisational performance. Part of this difficulty arose from the fact that cause-effect relationships are not easy to establish in complex systems. Another element of difficulty was the fact that the impact of changes in the system is only reflected in organisational performance months and even years after the change has taken place.

Some companies keep records of all the projects undertaken with the purpose of managing knowledge. These records usually contain a description of the projects, the main achievements and the causes of success or failure. The projects could be classified according to their complexity and uncertainty and the strategies followed, and the data could be analysed looking for correlations between the strategies used and the success of the project. This approach is an alternative which allows data to be collected in a short period of time, facilitating the study and allowing statistical analysis.

b) Hybrid Strategies

The case studies revealed that the generic strategies are not used independently, but usually combined to deliver the expected results. The information collected does not allow conclusions to be drawn about the effects of the interaction between the different strategies and the effectiveness of hybrid strategies, since this was not the purpose of this research. Following a similar approach to the one described in the previous section, using knowledge management records to analyse projects, it would be possible to study the use of hybrid strategies in different situations.

c) Other industries

Exploring the application of the model in other industries is a potential area for further research. This would help to test if the model is valid for other industries and could potentially help to identify other strategies.

This research was of an exploratory nature aiming to develop the model. Future research could test the model in different contexts and other research approaches, such as surveys that allow much larger samples, could be used.

d) Explore unpredictable region

Exploring the unpredictable region of the model is another area of opportunity for further research. This would include testing whether self-organisation prevails in this region and whether there are other strategies in operation. This could be done by actively looking for cases with a high probability of falling into this region and then classifying their strategies. This might require exploring other industries, such as the semiconductors or the personal computer industries, which are known to operate in highly unpredictable environments.

e) Sub-strategies

The generic strategies that form the model are only broad categories that can help to group different management approaches and each one can be broken down into a number of sub-strategies. Planning, for example, can be broken down into the different schools discussed in submission 9, such as those of design, environmental, cultural and learning schools. It should be possible to position these sub-categories in different areas of the model depending on the levels of complexity and uncertainty to which they apply. Further research could help to achieve this sub-categorisation of the generic strategies.

Each of the generic strategies has been studied in detail by other researchers and it is possible to find in the literature, categorisations of sub-strategies. By looking in-depth at each sub-strategy and by analysing how each relates to complexity and uncertainty it would be possible to create a more detailed model.

Glossary of Terms

Automation: [1] *The substitution of human physical and mental work by the work of machines* (Cox, et. al. 1992); [2] Automatic control of the manufacture of a product through a number of successive stages; the application of automatic control to any branch of industry or science; by extension, the use of electronic or mechanical devices to replace human labour (OED, 1989c)

Algorithmic Information Content (AIC): *It is a measure of complexity that considers the length of the shortest program that, using a universal computer, can generate the description of an entity* (Gel-Mann, 1996)

Chaos: [1] *Aperiodic bounded dynamics in a deterministic system with sensitive dependence on initial conditions* (Kaplan & Glass, 1995): [2] Stochastic behaviour occurring in a deterministic system (Stewart, 1989);

Co-evolution: *The interdependent evolution of "species" that interact "ecologically". The interactions may be antagonistic (consumer-resource) or cooperative (mutualism). Because each "species" in the pair is an important component of the environment of the other, changes in one select adaptive responses in the other, and vice versa* (Ricklefs, 1990)

Complexity: [1] A whole comprehending in its compass a number of parts, (in later use) of interconnected parts or involved particulars; a complex or complicated whole (OED, 1989a); [2] A set of both complicated and simple problems that are not reducible (Glouberman et. al., 2002; Goodwin, 1994) [3] **Crude:** A measure of complexity that quantifies the information required to describe a system, this is, the length of the shortest possible message (Gel-Mann, 1996); [4] **Effective:** A measure of complexity that focuses on the AIC of the regularities of an entity, as opposed to its incidental features (Gel-Mann, 1996); [5] ***Organisational:*** *refers to the perceived variety of entities, relationships, rules and behaviour that an organisation can exhibit*

Complexity Theory: [1] *The study of the behaviour of macroscopic collections of such units that are endowed the potential to evolve over time* (Covney & Highfield, 1995) [2] Complexity refers to the condition of the universe which is integrated and yet too rich and varied for us to understand in simple common mechanistic or linear ways. We can understand many parts of the universe in these ways but the larger and more intricately related phenomena can only be understood by principles and patterns –not in detail. Complexity deals with the nature of emergence, innovation, learning and adaptation (Santa Fe Group, 1996)

Complicated: [1] Folded together; [2] Tangled; [3] Consisting of an intimate combination of parts or elements not easy to unravel or separate; involved, intricate, confused; [4] Complex, compound: the opposite of *simple (OED, 1989);* [5] *A collection of simple problems which can be dealt with independently of each other* (Glouberman & Zimmerman, 2002)

Control: *the management approach that attempts to guide the organisation towards certain objectives, within certain limits of a standard or plan through the use of feedback.*

Emergence: *The properties of a system which are beyond the properties of any of its components. These are known as emergent properties — they emerge from the system when it is operating* (O'Connor et. al., 1997)

Feedback: *a process by which information generated by an action is used for the decision-making or regulation process, to affect the next action* (Stacey, 1996a).

Non-linear: [1] *involving terms of an equation that are not of the first degree; involving or possessing the property that the magnitude of an effect or output is not linearly related to that of the cause or input* (OED, 1989d); [2] the behaviour of systems when effects are not proportional to causes.

Non-linearity: *The property of not being linear; lack of proportionality between two related quantities (as input and output).* (OED, 1989d);

Plan: [1] To make a plan of (something existing, esp. a piece of ground or a building); to delineate upon or by means of a plan; to plot down, lay down (OED, 1989e); [2] *To devise, contrive, design (something to be done, or some action or proceeding to be carried out); to scheme, project, arrange beforehand* (OED, 1989e)

Planning: [1] The action of the verb plan; the action or work of a planner; the forming of plans; the making or delineation of a plan or diagram; scheming, designing, contriving (OED, 1989e); [2] *An attempt to deal with a situation when "it is believed that unless something is done, a desirable future is not likely to occur; and that if appropriate action is taken, the likelihood of such a future can be increased* (Ackoff, 1981); [3] A range of approaches intended to deal with the future of the organisation.

Self-organisation: *The spontaneous formation of interest groups and coalitions around specific issues, communication about those issues, cooperation and the formation of consensus on and a commitment to a response to those issues.* (Stacey, 1993)

Simplification: [1] *A strategy concerned with the removal of the sources of complexity and waste in organisations* (Gregory and Rawling, 1997); [2] The action or process of simplifying or rendering less complex or elaborate; the result of this (OED, 1989f).

Uncertainty: [1] *Uncertainty refers to the perceived variety of states in the environment, the perceived degree of change and the amount of knowledge about these states for a particular system*; [2] The quality of being uncertain in respect of duration, continuance, occurrence, etc.; liability to chance or accident. Also, the quality of being indeterminate as to magnitude or value; the amount of variation in a numerical result that is consistent with observation (OED, 1989b); [3] The average number of binary decisions a decision maker has to make in order to select one out of a set of mutually exclusive alternatives, a measure of an observer's ignorance or lack of information (Klippendorff, 1986).

List of Acronyms

ADD: Acceptable deferred defects
AIC: Algorithmic information content
BA: British Airways
BMI: British Midland
BMI-E: British Midland Engineering
BOM: Bill of Materials
BPR: Business Process Reengineering
CNC: Computer Numerically Controlled Machines
CPS: Carrier Payment System
CT: Complexity Theory
CXD: Complexities of Product Definition Project
DEALIS: Distribution and Logistics Information System
DES: Discrete Event Simulation
FMS: Flexible Manufacturing Systems
GA: Genetic algorithm
IT: Information Technology
MPC: Machine & Process Centre
MRP II: Manufacturing Resources Planning
NPD: New product development
OSRS: Outbound Shipments Reporting System
PS&L: Parts Supply & Logistics (A division of Ford of Europe)
SCM: Supply Chain Management
TDR: Technical Dispatch Reliability
TDRM: Technical Dispatch Reliability Model
TRT: Turnaround Time
VAT: Value added time
WIP: Work in Progress

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9 Appendices

Appendix 1: Samples of Interview Protocol and Questionnaires

a) British Midland Interview Protocol

Opening Remarks:

- Explain purpose of the research
- Ensure confidentiality of information

I. General Questions

Name: ______________________ Job title: ________________

E-mail: ______________________ Telephone: ________________

1. What are your main responsibilities?

II. Performance Measurement

2. What are the main indicators of the performance of the business?
3. How do you know when you are contributing to the success of the organisation?
4. What are the main indicators of performance for your job responsibilities?

III. Current Report

5. Do you understand the information in the current report?
6. Do you find the information in the report useful for performing your job?
7. Can you give your opinion on each of the elements of the report? (go through the current report with interviewee)
8. Is there any important performance information that it is missing fro the current report?
9. Are you involved in the production of the current report by supplying data, producing tables or graphs?
10. Can you describe your involvement in the production of the report?

Opening Remarks:

- Explain next steps of the research
- Thank for their time and support

Note: This questionnaire was used with the six employees of the Commercial Division of British Midland Engineering (the main focus of the study). Slightly different questionnaires were used with the internal customers and the director of the division.

b) Interview questionnaire used for the CXD project

1. How free do you think you are to explore the design space?
2. How precise are the design specifications as received by the design team or member?
3. Where do these specifications come from?
4. Are specifications 'written in stone' or is there room for negotiation?
5. Is there a dialogue with the (external) customer? (or is there only discussion among internal staff?)
6. How is the design process initiated? (Do you start with a previous design or with a clean sheet of paper)
7. Is there a set of possible final designs from day 1? (or is there process focused incrementally refining the best option?)
8. How might the search process be characterised? (Is it testing and rejection or simply the voice of experience?)
9. How many prototypes are constructed? (at what scales... to test what performance parameters?)
10. What attributes of the product are typically developed during design?
11. Is the extent of the design envelope known? (How do they know/understand what is possible as compared with what is required?)
12. How do you know that what you're designing is possible (in production, cost and performance terms)?
13. What are the limiting factors in terms of heat exchanger design?
14. Do you ever design a product that is beyond the specifications? (If so what happens to the additional knowledge?)
15. What are the temporal restrictions on design?
16. How tight are the deadlines? (how many formal hoops does the design have to jump through?)
17. What is the process through which the concepts (if there is one) is formalised?
18. Do individuals have responsibility for 'passing' or authorising stages of the design process?
19. Are new ideas taken form suppliers? (If so, how is this process managed?)

20. How much consideration is given to design modularity? (making the product useful for other applications)
21. How and to what extent has the application of software environments changed the design process?
22. How do cost legal and manufacturing criteria interact with the design process?
23. How much time do you actually spend exploring design alternatives?
24. How much is there with the company for 'blue sky' search?
25. To what extent is the final design a 'self fulfilling prophesy'? (do they actually search for the best solution or are they concerned with satisficing?)
26. Do staff get assigned specific tasks? (how disaggregated is the design process?)

Note: this questionnaire was used with 5 people in areas of design, purchasing manufacturing and sales within HS Marston. These interviews were not designed nor applied by the researcher, but full transcripts were available for analysis.

Appendix 2: Interview Summary Report (Sample)

Name: Tony Helliwel Date: 8/6/98

Position: Commercial Division Director

1. What is the vision of the department and how does it contribute to the organization?
   - "We are a supply chain company dedicated to the replacement of parts on airplanes"
   - "Our product is aircraft availability. To give back the plane as FAST (AOG's) as possible and in PERFECT CONDITIONS (CFDs)

2. What are the key issues of performance in the department?
   - In order to be effective you have to have the materials and the people at the right time in the right place
   - The predictability of failure is low so you have to keep more stock that what you are going to need.
   - Once you manage the stock more effectively, there are two options, to reduce your stock or to make the company grow. We are going for the second option.
   - Materials are 50% of the cost of a maintenance contract. That is the magnitude of the issue (example of recent bid for BA)
   - Benchmarking suggest that we are not good or bad for the industry. This means tat we have massive opportunities on applying very simple things (tools and techniques). We don't need anything sophisticated to stay ahead of the competition.

3. What do you think about the current MOPs report?
   - You get what you measure, that is why is very important to get the right measures
   - We have hundreds of measures, but not necessarily the right ones
   - We do not have measures in key areas:
     a) Price: we don't measure price change and we should be measuring it.

b) Expenditure on Materials: How much have measures on the performance of suppliers (suppliers rating or assessment). Particularly with key suppliers like Bedeck.

c) Inventory Measures:

- Total value of inventory (very difficult to assess)

- Inventory turns (we should be having about ½ turn/year, the target should be around 3 or 4 turns/year)

d) Payment Performance: We have to measure payment performance. The process is ineffective and some work has to be done. It is a big problem if we don't pay on time, vendors stop supplying then it becomes a problem.

4. Do you have any other problems related to MOPs
   - Another problem with the MOPs is that we are not sure if the current ones are accurate enough. Our internal customers don't believe us. W also have to review our targets, probably we need to have much higher targets.
   - We need measures that don't set one group against the other (commercial vs. technical.
   - I have no problem with global measures (that measure the performance of to groups together)
   - The process should also be systematized. In this company everything is pen and paper.

Note: This summary refers to the initial scopeing interview for the Measures of Performance project with British Midland. The purpose was to get a general overview of the impressions of the Tony Hellywel (director of the department) of the main issues related to the project. This was the very first interview of the entire research.

Appendix 3. Notes from Observations (BA-TDR Project Sample)

Notes from the meeting on the 18th of October at Compass Centre, Heathrow.

Present:

Chris Bowles	British Airways
Ken Johnson	British Airways
Carlos Mena	WMG
Linda Whicker	WMG

Overview of the Planning Process at BA

Ken Johnson explained how the overall planning process operates from its highest level to the actual operation and how the different systems fit into this process (see figure 1)

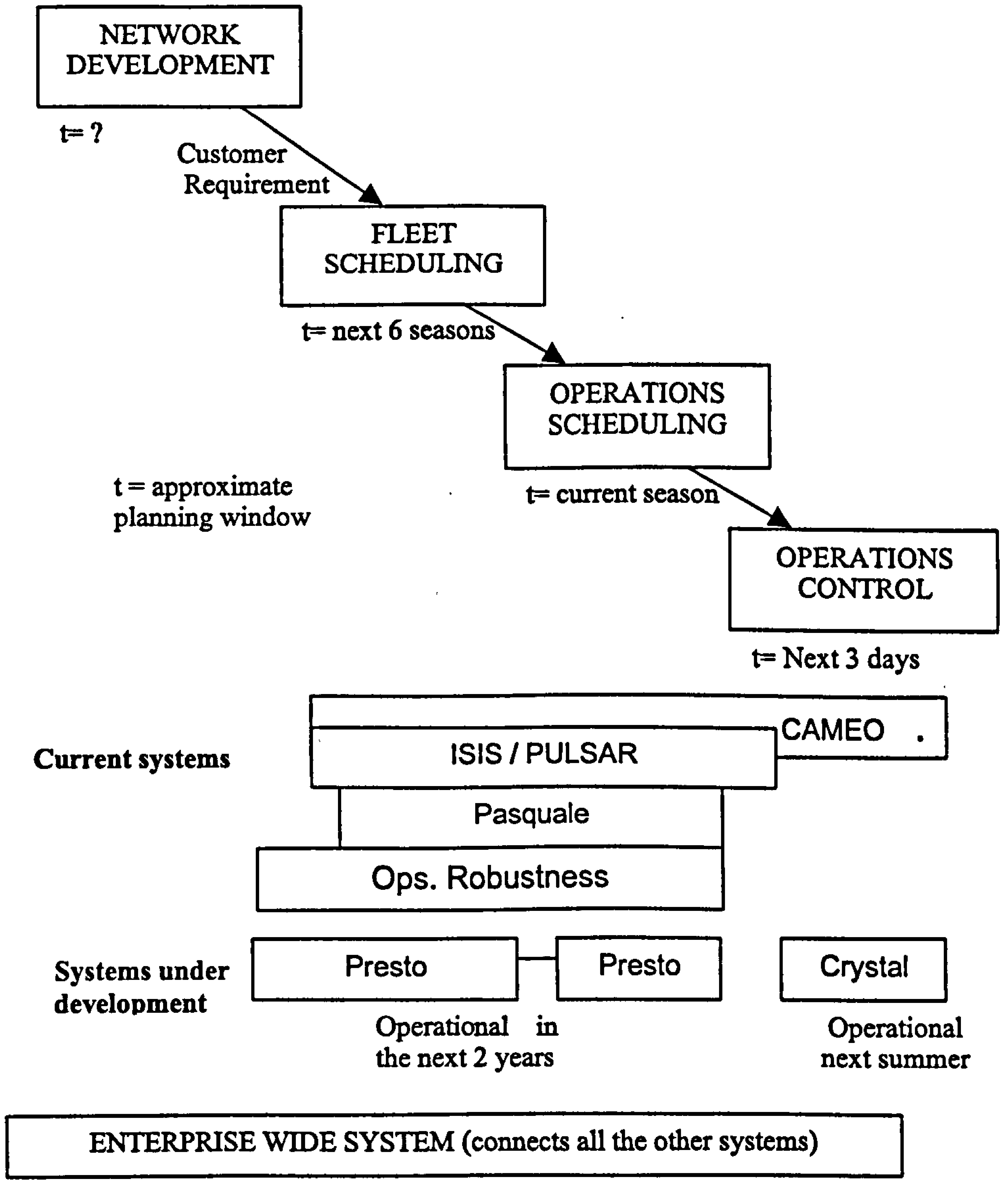


Figure 1. BA Planning and Scheduling

The uses and functionality of the different computer systems were briefly discussed (the purpose of the meetings on the 25.10.99 will be to analyse each of them in more detail). The following the main comments made about each of the systems:

a) Operations Robustness Model:
   - This model is used to compare different schedules helping to decide which one is the most suitable.
   - It does not generate schedules.
b) ISIS
   - Scheduling tool
   - Considers some constrains
   - It's old and not very reliable

c) Harmony
   - Planning tool under development
d) Pasquale
   - Supports scheduling
   - Constraint based system (considers only high level constraints)
   - Helps to take into account some of the engineering measures
e) PRESTO
   - Overall Planning/scheduling system
   - Under development (will be ready in approximately 2 years)
   - Will tell you if a schedule is workable or not, but only uses 10% of the constraint data (otherwise it would be very slow)
   - It has been tested in TBA
   - Will allow maintenance scheduling
f) CAMEO
   - Engineering Planning System
   - Helps to forecast and plan where maintenance is due
   - Allows limited what-if analysis
g) CRYSTAL
   - Will be used for the controlling the operation
   - Under development (will be ready in approximately 6 months)

Notes from the series of meetings on Monday the 25th of October held at British Airways Compass Centre.

As a result of the meeting on the 18th of October a need for a series of meetings to understand the operation of the different systems was identified. These meetings were carried out a week later. The main systems reviewed were Pulsar and ORM although some comments were also made about Pulsar, Pasquale, and ISIS. The following is a summary of the main points regarding each of the systems.

Session 1: PRESTO (Robert Urqhart)

- The meeting started by discussing the huge complexity of processes and systems within BA. It was mentioned that just for the planning process there are around 25 different computer systems that interact at different levels.

- Presto is the first deliverable of a larger project called "Harmony". Harmony will be a single planning system concentrating all the planning processes. The next deliverable as par of the Harmony project is an intelligent scheduling system that will interact with ISIS and CAMEO.
- Presto is a macro tool that can help to evaluate options (schedules) relatively fast. It does not compare or generate schedules, but only evaluates them. It is more of a credibility checker rather than a feasibility checker.
- The system allows you to play with the data, testing different scenarios and uses a colour code (green, amber, red) to point out when constraints broken or close to be broken.
- Presto takes all the date from ISIS the main scheduling system (discussed later)
- The departments that make use of the Presto are aircraft planning, airport planning and network development.
- To analyse schedule, presto evaluates five high level constraints over the pick week of a season. The constraints are:
    1. Slots
    2. Terminals
    3. Stands
    4. Aircrafts
    5. Maintenance
    6. (A macro will be included later to consider Crew constraints)

- It is important to note that maintenance is not really a constraint, and is not presented as broken/ not-broken. The only output of the system is the number of hours of maintenance required.
- In terms of Maintenance the following issues are considered

Issue	**Driver**
Majors	Fleet size
Mods.	Fleet size
Paint	Feet size
Minors	Flying hours
MCU[2]	Take offs – landings
T/Rounds	Not invoked in first release
Causality	Not invoked in first release

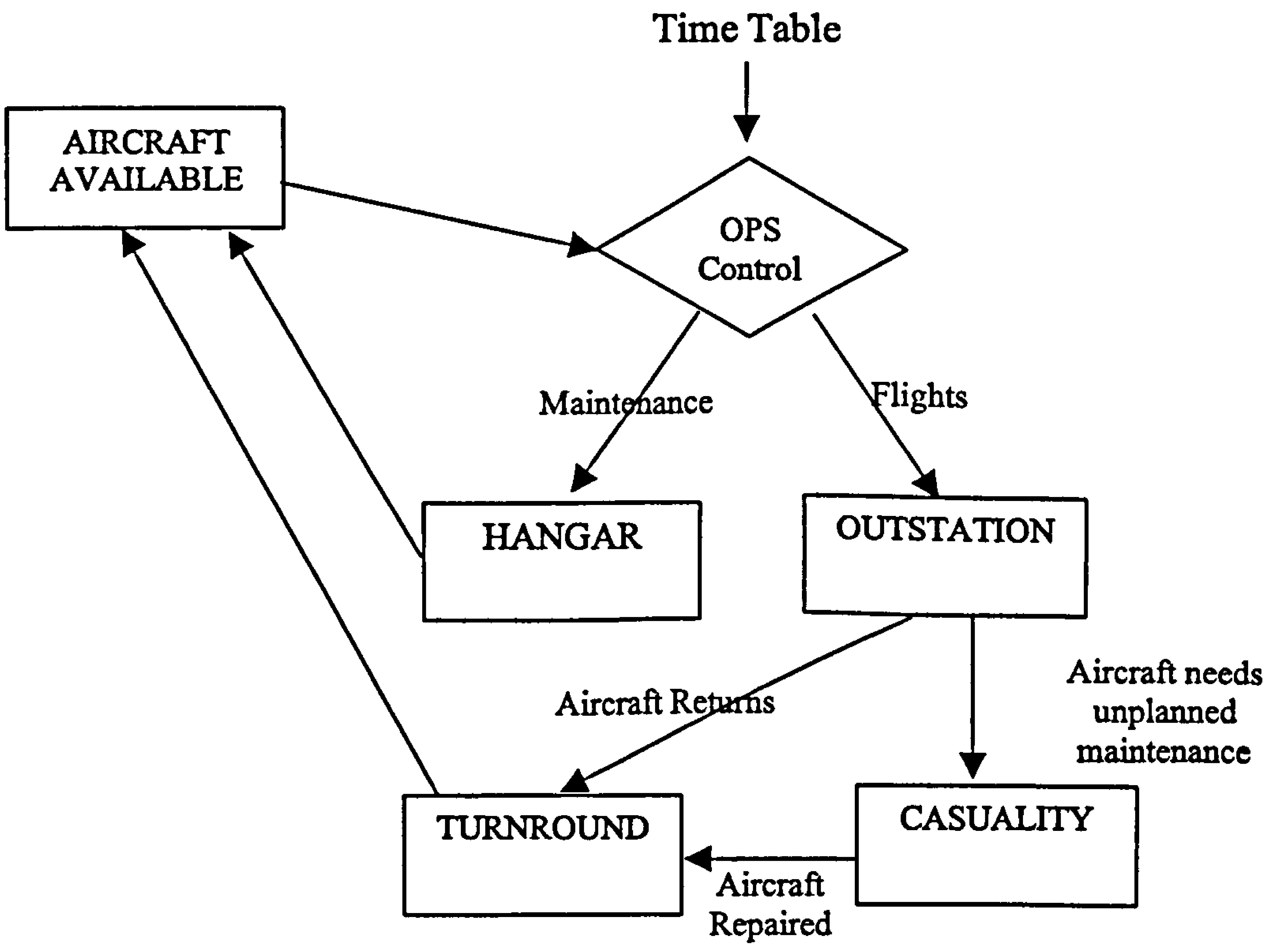
- There are two systems that were developed in collaboration with Imperial College that use constraints logic to support scheduling. These tools are Aircraft Swapper and Aircraft Replacer.

Session 2 – Operations Robustness Model – ORM (Graham Easton, Barry Graham and Dick Chapman)

- ORM is a simulation developed in Witness with the purpose of evaluating the results of a given schedule, based on the previous season data.

[2] MCU = Maintenance Clean-ups

- INPUTS:
    - Flights
    - Planned maintenance
    - Historic performance (previous season / disruption data)
        - Departure delays; by feet and time of day (actual numbers not distribution)
    - Roundtrip deviation – by time of day
    - Overrun of planned maintenance- by fleet
    - Causality rates and duration – by fleet
- SOURCE OF INFO: The main source of the information is DESC system (Defect Information Serviceability Control). It was mentioned that the information in this system is not very reliable and only some of the errors can be picked up.
- RULES IN MODEL
    - Simulates decision making process of Op's controller (very high level)
    - Makes fleet substitutions and cancellations
- OUTPUTS
    - Number of substitutions
    - Number of cancellations
    - Average departure delay.
- HOW THE SYSTEM WORKS



- It was discussed during the meeting that this system performs the main tasks that would be required to simulate TDR performance and could serve as a starting point for the new system.

PULSAR (Nick Davis)

- Pulsar is a graphical representation of the schedule. It is used for tracking actual vs. planned schedules.
- The information use by Pulsar comes from ISIS
- This system will be eventually replaced by Crystal

Pasquale (Christine Bowles)

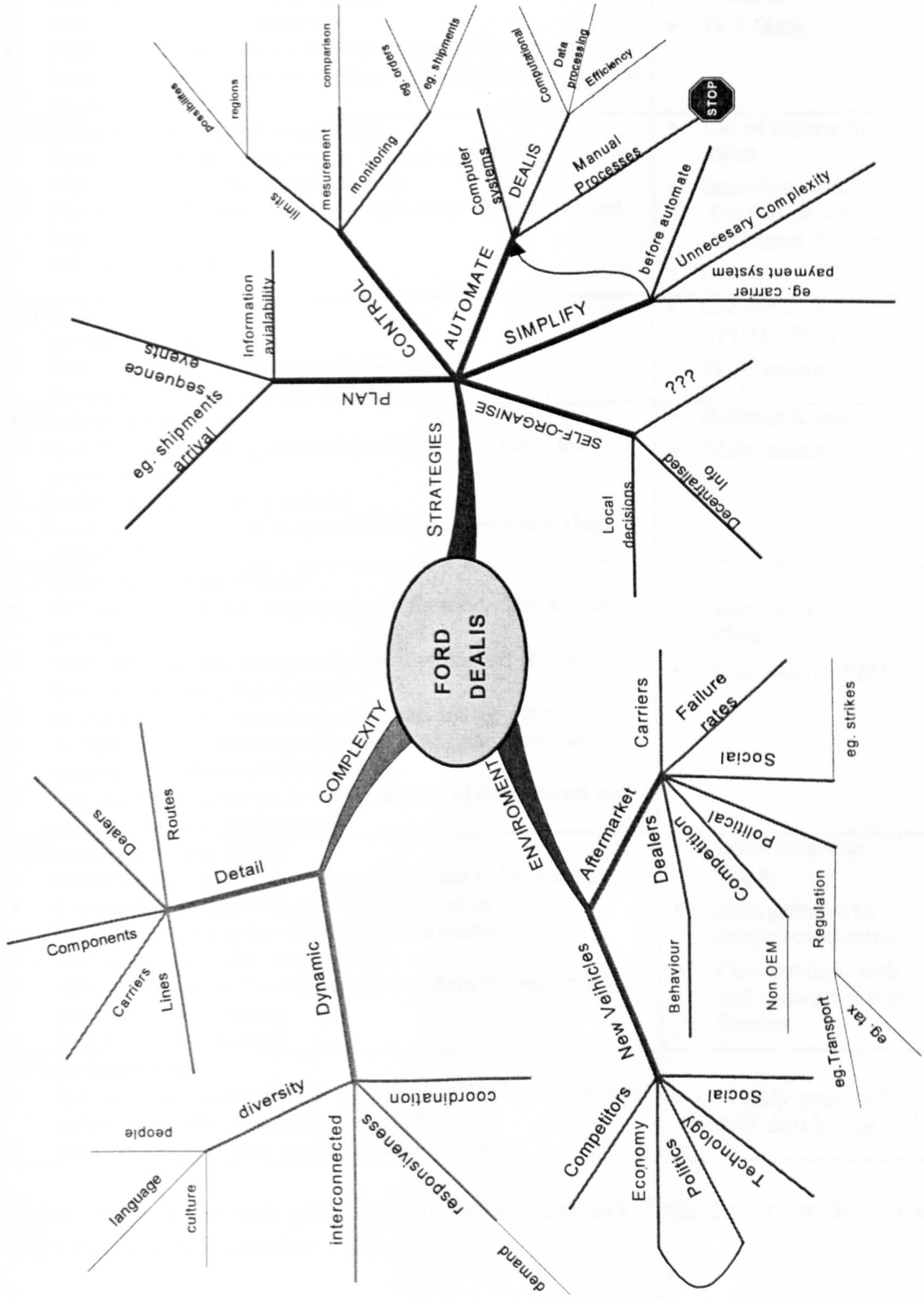
- The system is used to perform quality checks on the schedules
- The schedule is run against number of criteria (critical constraints). Based on the pick week, the system will show you when constraints are being broken.
- The input from engineering with regard to the constraints being evaluated was not very clear.
- The system allows making comparisons between different schedules.
- Apparently the system is not being used.

ISIS (David Smith)

- ISIS is the main scheduling software. It has two main inputs, the commercial requirements and the engineering requirements (base maintenance)
- The system does not do the scheduling. It only presents the requirements data and the planners have to create a plan trying to satisfy as many requirements as they can. The process is driven by the expertise of the users.
- More information is required with regard to the engineering input and the actual process followed to arrive to a final schedule.

Appendix 4. Within-case analysis tools (Samples)

a) Mind Map (Sample from DEALIS Project with Ford)



Note: this mind map was produced in January 2001 as part of the analysis of the DEALIS project conducted with Ford.

b) Matrix (Sample from British Airways TRT Project)

Areas of Opportunity	Support Information
1. Process ▪ Continuous delays along the process ▪ Multiple changes of ownership ▪ Value added time is only a fraction of total process time ▪ According to customers service has improved over the year but not enough.	▪ General Process Diagram ▪ TRT Maps
2. Planning, Scheduling & Sequencing ▪ Current sequencing rules are not focused on reducing Time or WIP. (Based on vitals and shortages) ▪ No use of MRP capabilities (poor data accuracy in BOM and stage sheets) ▪ Almost no forecasting	▪ List of sequencing rules ▪ Interviews with Production Unit Managers (PUMs) ▪ Interview (DK)
3. People ▪ Overtime dependence ▪ Fear for jobs if WIP continues decreasing ▪ Specialised workforce (lack of flexibility)	▪ Conversations (PUMs, RM) ▪ Skills matrix
4. Bottleneck Resources ▪ Jig boring and grinding are bottleneck resources (limit the maximum output) ▪ Bottlenecks are not fully utilised ▪ Few people knows how to operate bottleneck resources (high sensibility)	▪ Bottleneck analysis ▪ Skills matrix
5. Performance Measurement ▪ TRT suffers when old components are finished. This should be rewarded! ▪ WIP promotes processing components with short processing time, leaving long ones behind. ▪ Shifting emphasis between one measure and the other ▪ Availability of components in stores is not considered as a measure (customer service measure) ▪ Important cost issues such value and float of components are not considered (cost measures)	▪ Interviews with PUMs ▪ Discussions (RM)
6. Cleaning & Crack Check ▪ Customers are demanding Turnaround Time to be reduced ▪ Components continuously get lost or mixed up ▪ Possibility of internal problems between workers ▪ Workforce needs close supervision ▪ All other shops ask for maintenance workers for help in other tasks other than cleaning ▪ Possible hidden demand	▪ Interviews with PUMs ▪ Data gathered by internal customers ▪ Conversations with unit manager Kevin Stanley
7. Sub-Contracting ▪ In some cases relatively high proportion of WIP is held at sub-contractors (16% on average, up to 25%) ▪ Sub-contracting can be used to replace Overtime	▪ Weekly graphs of WIP distribution

Note: This matrix was produces for the Turnaround Time project with British Airways around December 1998