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The Coevolution Of The Firm And The Supply Network:
A Complex Systems Perspective

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ABSTRACT

A complex adaptive systems approach has been permeating organizational studies and the field of supply network management helping to describe and explain supply network dynamics and emergent inter-firm structures. This has improved our theoretical knowledge of the nature of supply networks transforming raw materials into products, within a constantly changing environment. From the early days of simple structures, describing bi-lateral, local arrangements between firms for the creation of relatively simple products, we are now in an environment of various supply network archetypes, describing different global sourcing regimes of highly integrated, sophisticated products within multi-tier networks.

This thesis is a study of the coevolution of the firm and supply network in the commercial aerospace manufacturing sector producing jetliners of 100 or more seats. One of the contributions of this research is to demonstrate how the holistic approach of complexity science can be applied to describe, understand and gain new insight into the coevolution of the firm and the supply network. Based on the findings of multiple interviews and questionnaires in eight global aerospace firms across multiple supply chain tiers, this research finds high-performing clusters of inter-firm characteristics, plus the aspects of structure and integration which deliver the supply network performance. Practitioners can use these specific results to examine their own firms and the new coevolutionary conceptual framework developed in the thesis may aid future research studies of complex adaptive systems in practice.

The simple survey design and analysis method used in the final research stage of this research, has the potential for use in other industries, markets and other complex adaptive systems generally to examine performance outcomes and the effects of having or adopting new inter-firm characteristics. Finally, implications for policy include the potential to legitimize supply networks in order to stimulate competition and innovation in the economy.

Keywords:

Environment; Inter-Firm Characteristic; Network Structure; Network Performance; Commercial Aerospace

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Undertaking this PhD has been immensely rewarding and in many ways I am sad that it is now over. I have been very lucky to find a philosophical position, and so a way of knowing things, that I believe in so strongly particularly as I was exposed to a single lecture that so captivated my interest as to lead to this PhD. My grateful thanks therefore go first to Ian McCarthy (now at SFU, Vancouver) who presented a lecture showing the evolutionary mapping of firms into organizational forms. Cladistics, the method he had used, was only a starting point into Complexity Science and I quickly made a connection with the Complex Systems Research Centre at Cranfield University and became immersed in a new vocabulary and understanding that has unfolded before me and never failed to disappoint.

I am enormously indebted to my supervisor Professor Peter Allen, for his direction, judgment, and giving me the freedom to explore (and I have, along many pathways). His insights into complex adaptive systems extend from his own PhD in physics, through to his many years with Ilya Prigogine (Nobel Prize winner for dissipative structures) to urban systems, learning and modelling. I am privileged to have worked with Peter. I thank also my colleagues in the Centre, for their conversations, suggestions and endless dialogues. For their consideration of my interim review papers and encouraging critique, I thank my panel: Professors Keith Goffin and Martin Christopher. Special thanks go to Heather Woodfield of the Kings Norton Library who has solved a myriad of bibliographical and referencing queries.

My grateful thanks also go to the firms and individuals who have participated willingly in the research and volunteered their information for the purposes of research advancement. Whilst they cannot be named here for confidentiality purposes, they are party to these results.

Finally, I dedicate the thesis to my husband Mike and thank my family for their patience, without which this work would not have been possible.

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1 INTRODUCTION

"Complexity shows up everywhere in our universe; it shows up in the cosmos and in subatomic systems, but it is perhaps most evident (and shall we way, most complex?) in biological systems and in the systems in which we human beings take part … two of these human systems: organizations and markets, (are) the principle organizers of most of our collective goal-oriented activities."

(Simon, 2001: 79)

1.1 Prelude

Our theoretical knowledge of the nature of the supply network has matured considerably in the last 20 years helping practitioners to understand how decisions, resources and behaviours might be deployed to improve survival and performance. This new knowledge makes the assumption that the supply network is a complex adaptive system (Choi et al., 2001; Surana et al., 2005) located within its own unique environment. Simon's quote (2001) at the introduction of this thesis, makes the important point that firms and markets are complex adaptive systems. Applying Simon to the supply network means that we can view the supply network as more than just a collection of firms.

The assumption that the supply network is a complex adaptive system means that we can use the tenets of complexity science to make sense of the dynamics, the evolution, the structure and the unpredictability of supply networks, as this thesis will reveal. However, the adoption of a complex systems perspective brings with it also multiple challenges. "*In part because the field has attracted a diverse set of researchers from different disciplines, but more importantly, because defining and measuring complexity is intimately tied up with difficult questions of ontology and epistemology, there is no consensus about how to define or measure complexity. Most fundamentally, a key question is whether complexity is ontological or epistemological: is it a property of a system, its parts and their interactions; or is it a property of a given interpretation, representation or simulation of a system? The emerging consensus is that it is both*" (Maguire et al., 2006: 170).

The issue of defining and measuring complexity is addressed in this thesis using a mixed methods research strategy (Brannen, 2005; Bryman, 2004). This strategy encompasses different research designs for different purposes, collecting qualitative and quantitative data for juxtaposition in an orderly way.

The metaphysical issues of ontology and epistemology are dealt with by recognizing that truth and knowledge areextracted along a continuum which evolves over time. This continuum has opposing and extreme ends in objectivism and in interpretivism (Maguire et al., 2006). The entire continuum is accommodated within a complexity systems perspective and sometimes brought together such in Daft and Weick's (1984) '*Toward a Model of Organizations as Interpretation Systems'*. The same attempt is made in this thesis, recognizing that the supply network is fundamentally an open system with a moving boundary interpreted locally by the agents within and without.

A further critical issue is to recognize that organization (both noun and verb), whether of a small firm, a multi-national enterprise or a loosely-coupled supply network, creates interventions in natural system dynamics. It is this intervention, which is more Lamarkian rather than Darwinian, often purported as rational, sometimes purposeful, often triggered by technological innovation that generates waves of creative destruction (Schumpeter, 1942) and novel structures and creates differences in performance and sustainability.

1.2 Rationale

The thesis is concerned with two aspects of the coevolution of the firm and the supply network: the dynamical characteristics of coevolution and the structural relationships of the characteristics to the supply network. This section describes the rationale for framing the research in a complex adaptive systems perspective.

1.2.1 Structure and coevolutionary dynamics

The emergent structures of the supply network which persist within the system, together with their associated behaviours, reveal the structural attractors of the system. These structural attractors are the outcome of coevolutionary processes between firms which are themselves multi-layer complex systems, nested within multiple other systems, open to influence from the environment and adaptive to change. In complex systems terms, the environment is merely another layer in a nested system in which each system takes every other system as its environment in a process of coevolution whilst adapting to their environment. The environment (or landscape) is changed as a result of changes in the systems that constitute the environment (Kauffman, 1993).

The supply network exists within an ecology of co-existing systems which are spatially distributed, have various patterns of abundance and have changing functional interactions over time. This study explores how the systems interact within a broad evolutionary framework of survival, growth, development, and reproduction and how factors in the environment are created or influence the structures of supply network that emerge. Evolutionary mechanisms produce qualitative change in a system. Qualitative change may be triggered by the system, the environment or in the interaction between them. We find that the context of the commercial aerospace manufacturing supply networks is changing rapidly. Through continued globalisation and the availability of transport infrastructure and electronic communications, the reach of even modest sized firms is extended into markets and resources not previously available, thus increasing variety and opening up greater possibilities for evolution.

1.2.2 Evolution, survival, and variety

Aldrich's evolutionary theory (Aldrich, 1999) recognises and incorporates relevant organizational theories such as institutionalism, resource dependence and transaction cost economics amongst others. Aldrich develops processes of evolution, namely variation, selection, retention, and struggle from Donald T. Campbell's work, based originally on Darwin (1859). Coevolutionary theory extends evolutionary theory further and focuses on competitive leadership positions, and how they are lost and gained over time (Murmann, 2003). Firms are in a constant state of flux, evolving, competing and importantly not in isolation.

The firm is nested within other bodies, including partnerships, regional economies, nations; and a firm itself has multiple nested sub-systems, including functions, divisions, teams, projects, individuals. Individuals belong to multiple systems, professional bodies, academic associations, social and leisure groups, etc. There is no notion of an isolated or standalone complex system: "*Nothing happens in isolation*" (Barabási, 2002: 7).

Supply networks are innately dynamic and responsive to the environment. When the dynamics of a supply network form a structure, it may indicate an underlying structural attractor which can be described in phase space (Capra, 2005). If the structure persists, it is a dissipative system into which energy flows, is catalyzed into a structure using some of the input energy and losing the remaining energy to the environment in the process of entropy production (Prigogine and Stengers, 1984). An example from the physical sciences is a cyclone in which interacting particles exhibit long range correlations. Abundant (plentiful) structures which survive are evidence of structural attractors that persist within the environment. These dynamic, flexing systems are influenced by both teleological intentions from within the system and stochastic effects based on the diversity within and outside the system. The nature of these interactions which cause emergence as supply network forms within the particular environment of the commercial aerospace manufacturing sector is the topic of the research, as are the network forms and archetypes of the sector.

A fundamental tenet of complex adaptive systems is that small differences in market share can be amplified and develop into much larger differences (Arthur, 1994). This requires self-reinforcing processes, that is positive feedback, to dominate self limiting processes or negative feedback which act as a self-regulatory mechanism and the key to equilibrium (Capra, 1996). A further tenet is that one action may have varying effects on different parts of the complex system and may result in varying degrees of feedback, driving virtuous or vicious cycles (Holland, 1998). In the language of self-organized criticality, when a system reaches a critical condition, a small and previously unpredictable change can catalyze a major change in the whole system (Bak, 1999). So firms and supply networks can change disproportionately to the cause, if the cause (and effect) can be identified! In a dynamic, self-organizing world with co-evolving systems and sub-systems, change and innovation become key features of organization life so the application of Complexity Science in organizational transformation is relevant (MacIntosh and MacLean, 1999).

A supply network is a dynamic network consisting of many agents acting in parallel and constantly acting and reacting to the actions of other agents, it is thus a complex adaptive system (Holland, 1995). The behaviour of the system arises from the decisions of many individual agents (Waldrop, 1992) in a complex interaction of competition and cooperation. When the self-organization within the system transcends the elements from which it has developed, then emergence occurs (Letiche, 2000). Hayek (1967: 26) associated emergence with new patterns, arising from the increase in the number of elements, describing how the large structure would "*possess certain general or abstract features which will recur independently of the particular values of the individual data, so long as the general structure is preserved*". Thus when the interactions of the agents in the supply network create (a new) order, we can observe and describe a qualitative difference from the previous order. Letiche (2000) further extends the argument by stating that emergence has only occurred if the structure of the system has changed so substantially that the "old" laws don't apply and a new world exists. Agent interactions create a new order and the new order is underpinned by a new regime of rules for future behaviour. The interactions are purposeful in that the agents develop strategies to optimize their functioning in their environment (Axelrod and Cohen, 2001).

A supply network form may emerge as a variation which is favoured (selected) in the environment thus retained and diffused within the population. Other forms may be ephemeral such as when a particular structural attractor cannot be embedded or if the form is not a good fit within its particular environment. The processes of evolution continue their search for new variations. Species co-evolve with the environment.

1.2.3 Alternative perspectives

The Resource Based View (RBV) of the firm provides an explanation of sustainable competitive advantage, which is defined as a "*value creating strategy not simultaneously being implemented by any current or potential competitors and when these other firms are unable to duplicate the benefits of this strategy*" (Barney, 1991: 102). This suggests the identification of a market niche that an organization can either create or exploit in a way which gives it advantage over its competition. In evolutionary terms this advantage is limited in time. Competitors find ways to imitate the firm or re-shape the niche to their own advantage. In a changing environment, sustainable competitive advantage needs to incorporate the rate at which the firm can identify new niches, exploit them and then adapt to the next niche, and so on as the environment continues to change. This means that experimentation is important (Allen, 1988) and that innovations and evolution fit within the wider milieu of the social, cultural, environmental and technological history: the "*eco-historical regime*" (Garnsey and McGlade, 2006).

Other lenses used to describe or explain supply networks tend to take a partial view favouring or prioritizing particular aspects of the phenomenon. Neo-classical economics gives prominence to the organization, extrapolating the past using assumptions that may not apply to the future of the modern evolving economic system (Ramos-Martin, 2003). Population ecology gives priority to the environment (Hannan and Freeman, 1977). The Resource Based View (RBV) of the firm (Barney, 1991; Wernerfelt, 1984) shifts the locus of competitive advantage from the environment to the firm's internal resources, in a process of equilibrium between firm resources and market demand in which the firm's value creating strategy is not imitable.

All such lenses treat environmental change as an exogenous variable (Baum and Singh, 1994). Exogenous variables are economic variables independent of the relationships that determine the levels of equilibrium. However, the environment is inter-leaved with the supply network and the firm to such an extent that arguably they cannot be separated.

A further complicating factor is that each firm interprets its environment differently. The assumption that all firms within one industry interpret the environment in a single way is false (Daft and Weick, 1984; Aldrich and Pfeffer, 1976) as managers can manipulate environmental features, for example, by political action (Child, 1972) and can change organizational designs (Goold and Campbell, 2002). Industry events can also reinforce or loosen network structures (Madhavan et al., 1998). Without the explicit inclusion of how the environment influences the firm and supply network and vice-versa, a single-lens view by definition can provide only a partial view of their evolution.

1.2.4 Summary

This section presented a rationale for the use of a complex adaptive systems perspective to address an enquiry into the coevolution of the firm and the supply network, and supply network structure. This perspective is not only deeply immersed in evolution and structure, but it is shown to have advantages over other perspectives.

The next section presents an outline of the research, its aims and research questions.

1.3 Research Outline and Aims

The importance of organizational evolution is evident in the myriad of challenges faced by organizations: globalization, business process re-engineering, performance and efficiency improvement, quality improvements, and customization, just to name a few. So the practitioner question is how best to structure an organization to fit its operational scope so that it is best placed to evolve as innovations and opportunities become available. If a firm is considered holistically, having a network of relationships within the environment, the economy (or market) and society at large, then how can this entity determine the formation, dissolution and re-formation of its boundaries in a manner that gives primacy to its evolution?

1.3.1 Research objective and phases

The primary objective of this research is to explore the coevolutionary dynamics between the firm and the supply network. In meeting this objective, it has been necessary to devise a methodological approach to connect theory to practice and to analyse empirical data in a way that can make a contribution to theory in the context of coevolving dynamical complex adaptive systems.

The research process involves synthesizing the literatures on Complexity Science, Evolution, Coevolution and Organization Theory with respect to emergence of supply network forms and the process of firm and supply network coevolution.

The research objective is met by undertaking three phases. The first phase examines extant literature on the nature of coevolution between firms and the supply network, Most of the literature does not focus on commercial aerospace manufacturing although supply chain literature can refer to manufacturing, so it is anticipated that there will be differences between the empirical findings and the literature. This phase also looks at the characteristics of the environment of the jetliner product. The second phase establishes the rationale for a mixed methods research strategy. From this, a research design is created and a number of research stages for data design, collection and analysis are planned and implemented to meet the needs of the research. The third and last phase analyses the data. This will include individual case studies, surveys, comparison of cases across the entire commercial aerospace manufacturing sector and by supply network tier. Conclusions will critique extant literature, state the contribution to knowledge, research limitations and suggestions for further research. The three phases are shown graphically in Figure 1-1.

1.3.2 Research questions

Each stage of the research has associated questions.

1.3.2.1 Research questions for phase 1

Q1: What is understood about the nature of coevolution between the firm and the supply network in the context of the commercial aerospace manufacturing environment?

Q1a: What are the characteristics of the environment?

Q1b: What network structures are evident?

Q1c: What are the characteristics involved in coevolutionary change?

1.3.2.2 Research questions for phase 2

Q2: What research strategy will help to describe supply network structures and the processes of coevolution?

> Q2a: What theoretical and metaphysical basis will meet the needs of the study?
>
> Q2b: What research design will provide insight and make a contribution to knowledge?

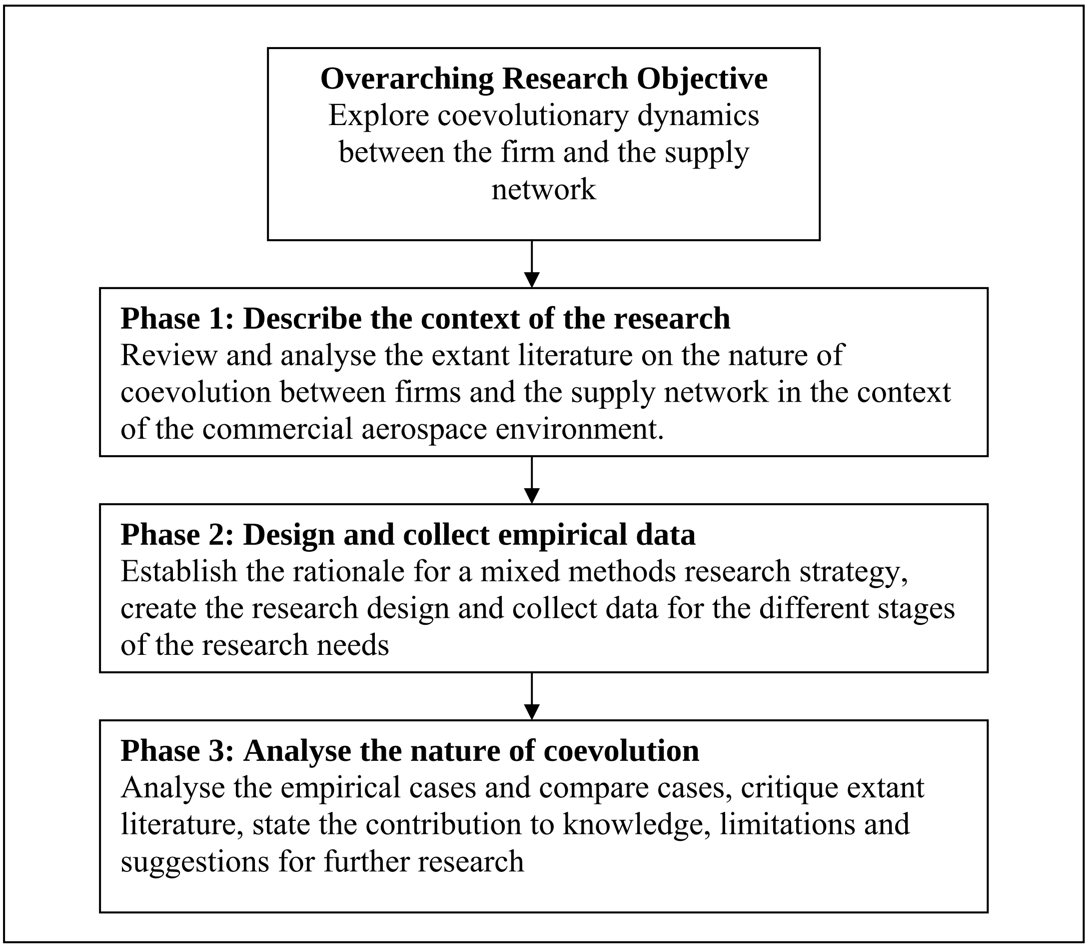


Figure 1-1 Research Objective and Research Phases

1.3.2.3 Research questions for phase 3

Q3: What are the inter-firm characteristics of aerospace supply network dynamics?

Q3a: What are the performance trade-offs in inter-organizational characteristics?

Q3b: What differences are there in inter-organizational characteristics at different tiers of the supplier network?

Q3c: How do supply chain dynamics relate to supply network structure?

1.3.3 Intended research outcomes

Each stage of the research has intended outcomes.

1.3.3.1 Phase 1 intended outcomes

- A review of the commercial aerospace manufacturing sector producing jetliners
- Identification of the dimensions of the environment of commercial aerospace manufacturing
- Examination of the broader global techno-economic environment
- A literature review of organization and supply network evolution
- Identification of supply network archetypes
- A visual history of the evolution of the aerospace manufacturing industry
- A draft of the inter-firm characteristics from the respective literatures.

1.3.3.2 Phase 2 intended outcomes

- A synthesis of evolutionary theory, coevolutionary theory and complex systems theory
- Research strategy
- Research design, with data collection stages
- Statement of analysis methods for each research stage
- The actual data collection

1.3.3.3 Phase 3 intended outcomes

- Identification of the nature of the supply network structure
- Description of the supply network dynamics and coevolutionary change
- Highlighting performance trade-offs in the adoption of supply network characteristics
- Highlighting differences in the supply network by tier

1.4 Research Gaps

This research attempts to contribute to a number of research gaps in existing literature and knowledge. These gaps are described in this section.

New supply chain structures together with techniques for comparing structural alternatives are in need of further study (Lambert et al., 1998). The evolution of networks and how they change over time remain outstanding questions (Madhavan et al., 1998) as does the examination of how competitive dynamics and network structure coevolve (Gnyawali and Madhavan, 2001). The importance of layers in evolution is an outstanding research problem, particularly how emergent properties of each complex system (e.g. a firm, a supply network, an industry), impact the next layer in the complex system (Fuller and Warren, 2006), enabling and constraining the potential for new emergent properties at the next layer.

The lack of appropriate methods to conduct Complexity research is a significant research gap and for this reason Question 2 is included explicitly, rather than leaving the question of methodology as simply a part of the thesis preparation process. A methodological contribution to the complexity and management literatures is presented in this thesis as a practical way to address complexity research.

In addition, the thesis also addresses the gap in empirical studies of complex adaptive systems which is an overall gap for the discipline, possibly as a consequence of the difficulties in finding practical research methodologies.

In their review of the evolution of organizational theory and supply chain management, Miles and Snow (2007) describe how their focus of research has evolved from strategic choice, through resource-based view of the firm and now to knowledge management in multi-firm network organizations. This thesis proposes that a complex systems perspective is a more evolved lens with which to describe and explain the coevolution of the firm and the supply network. Further Miles and Snow state there is a research gap for new theories of inter-firm organization and collaboration which can exploit knowledge, not just traditional goods based networks, and can contribute to national or regional longer term economic development.

The development of the coevolutionary conceptual framework which provides an answer to question Q3c: "*How do supply chain dynamics relate to supply network structure*?" is a conceptual contribution to the Complexity and management literatures. In particular it has potential for developing a new theory to explain the coevolution between layers of complex adaptive systems.

1.5 Planned Research Contribution

This section describes the planned research contribution. The actual research contribution is provided in detail in Chapter 8.

Contribution to academic theory

- affirm relevance of complexity theory to supply network evolution
- nature of supply network archetypes
- coevolutionary dynamics that change structures of networks
- conceptual coevolutionary framework between socio-economic systems
- environmental and historical importance of network evolution

Contribution to the methodology of network research

- use of multi-methods strategy to support identification of important variables for study
- use of first order and pair-wise effects to describe the actual performance of the supply network

- identification of relevant integration methods between firms enabling coevolutionary dynamics

Contribution to the theory of practice

- relevance of performance trade-offs embedded in the supply network
- opportunities and limitations of supply network forms
- opportunities and limitations of coevolutionary dynamics
- limitations to knowledge and decision making

1.6 Structure of the thesis

Table 1-1 sets out the structure of this thesis, providing a summary of the scope and intended outcomes of each chapter. Phase 1 is addressed in chapters 2 and 3, which look at the environment and the literature respectively. Chapters 4 and 5 achieve Phase 2 of the research, which set out the theoretical basis and research strategy for addressing the research questions. Phase 3 reports and analyses the data collected during the study, and draws conclusions, makes a contribution, sets out limitations and suggestions for future research.

Phase	Chapter	Scope	Outcomes
1	2 THE ENVIRONMENT OF THE AEROSPACE INDUSTRY	Industry context, history and future	Environmental characteristics
	3 FIRM AND SUPPLY NETWORK LITERATURE	Literature review, organization and firm evolution. supply chain, and network relationships	Supply network archetypes Inter-firm characteristics Cladogram
2	4 THEORETICAL FRAMEWORK	Evolutionary and coevolutionary theory, complex adaptive systems perspective	Rationale for theoretical perspective
	5 RESEARCH DESIGN AND OPERATIONALIZATION	Mixed methods research, appropriate techniques for the design, collection and analysis of data	Research strategy Research design Data collection stages Collection of empirical data
3	6 AEROSPACE CASE STUDIES	Prime, first tier and second tier commercial aerospace firms	Analysis of cases
	7 AEROSPACE QUESTIONNAIRE SURVEY	Survey data analysis	Comparative studies by supply network tier, by performance and by survey table sub-sets Results for the industry
	8 CONCLUSIONS & REFLECTIONS	Examination of results with respect to existing literature	Dimensions of supply network structure Description of supply network dynamics and coevolutionary change Statement of performance trade-offs and differences in supply network tier

Table 1-1 Research Phases and Thesis Structure

1.7 Summary

This chapter has served as an introduction to the thesis. It has identified the field of research as the commercial aerospace manufacturing sector. A complex systems perspective is taken as it provides a richer description and understanding of the dynamics, evolution and structure of supply networks than any other single perspective, importantly also taken into account the environment of the supply network. Coevolutionary theory is the basis for understanding the inter-dependent and mutually adaptive processes between firms and the supply network.

The next two chapters address the first stage of the research, which is to review and analyse the extant literature on the nature of coevolution between firms and the supply network in the context of the commercial aerospace environment. The main research question for this stage is to answer Q1: "*What is understood about the nature of coevolution between firm and the supply network in the context of the commercial aerospace manufacturing environment*?"

2 THE ENVIRONMENT OF THE AEROSPACE INDUSTRY

"Progress has not followed a straight ascending line, but a spiral with rhythms of progress and retrogression, of evolution and dissolution."

Johann Wolfgang Von Goethe
1749-1832, German Poet, Dramatist, Novelist

2.1 Introduction

This chapter considers the environment of the industrial sector of the commercial aerospace industry making airliners. It takes a brief look at airliners and in particular jetliners, the behemoths of commercial aerospace manufacturing. This is followed by a review of the environment of aerospace manufacturing, identifying the environmental characteristics that have influenced the nature of commercial airliners. The chapter concludes with a look at industry expectations and an analysis of the dimensions of the environment.

2.2 Commercial Airliners

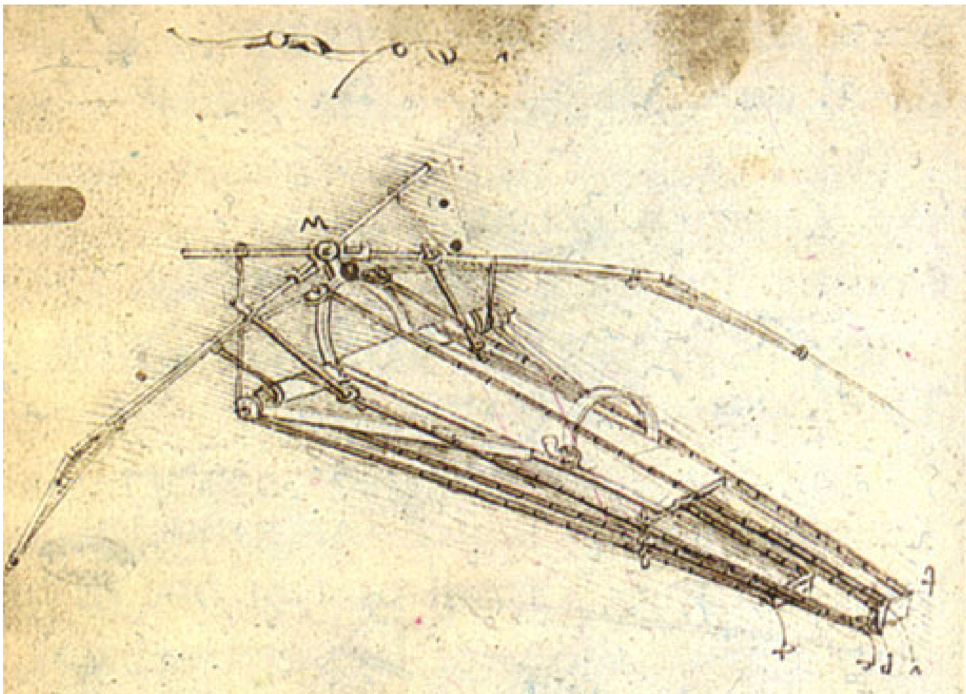


Figure 2-1 Leonardo da Vinci: Design for a flying machine, (c. 1488) Institut de France, Paris

Whilst assisted personal flight was not achieved until the 20th century, many, including Leonardo da Vinci (1452-1519) (see Figure 2-1) were fascinated by the phenomenon of flight and expended effort on the design of flying machines (Open Site Foundation Inc., 2006). George Cayley (1773-1857) known as the "Father of Aviation" and the "Father of Aerodynamics" was a pioneer, identifying the four aerodynamic forces of heavier-than-air flight: weight, lift, drag and thrust and their relationships, and designing aircraft (see Figure 2-2) (Freeola, 2008c). In 1849, Cayley was the first to design and build a heavier-than-air aircraft to carry a person (Open Site Foundation Inc., 2006).

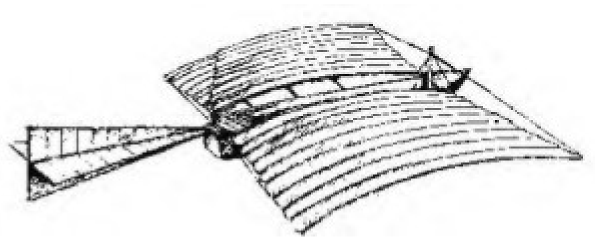


Figure 2-2 George Cayley's 1799 design of an aircraft

The first airliner, the Benoist XIV, was produced in 1913. It was followed in 1919 and successive years by several airliners manufactured by firms which are recognized names in flight travel, including de Havilland, Vickers, and Fokker (Freeola, 2008a); see Figure 2-3. The Junkers F-13 was the first passenger plane to fly world-wide in the 1920s.

2.2.1 Jetliners

Modern day commercial airliners are powered by turbofan jet engines which are quiet and fuel-efficient, unlike the first generation of airliners such as the de Havilland Comet, Sud Aviation Caravelle, Tupolev Tu-104, Boeing 707, Douglas DC-8 and Convair 880. Modern airliners or jetliners used for passenger travel are also distinguishable by distance (long- and medium- haul), size (wide and narrow body) and by the numbers of passengers carried. This thesis is concerned with the organizations producing airliners carrying at least 100 passengers, and their suppliers. Such airliners were not manufactured until the end of World War II, the first being the Lockheed Constellation in 1943, and the Convair 880 and Boeing 707 not until the late 1950s.

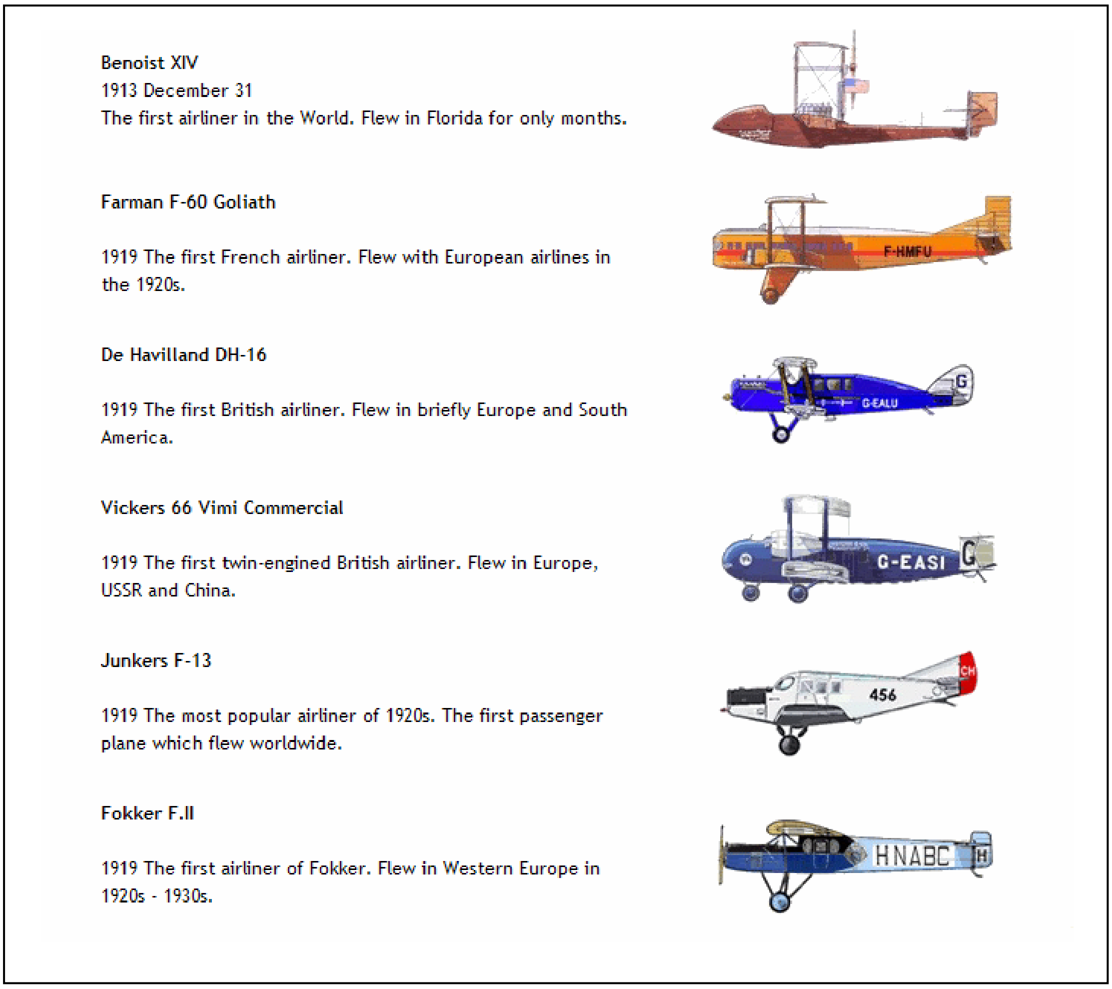


Figure 2-3 Introduction to the first airliners

Most of the early organizations producing airliners are not of direct interest, except to note that many have been the subject of a series of acquisitions so that they are today part of the largest organizations. An example of this is Convair (US Centennial of Flight Commission, 2003) which itself was formed in 1943 creating one of the world’s larger aircraft manufacturers of the time; and which was acquired by General Dynamics in 1953 forming a new division of which the aero-structures part was in 1994 acquired by McDonnell Douglas, now part of Boeing.

The first airliners of 1920s bear little resemblance to the jetliners of today. The largest commercial airliner was built recently in 2005 in Toulouse, France. The A380 Airbus (see Figure 2-4) seats 555 people but can carry up to 853 passengers although the first A380 go to into commercial use by Singapore Airlines had just 471 seats (Bridge 2007).

Figure 2-4 The Airbus A380

The Dreamliner 787 is the latest airliner from Boeing shown in Figure 2-5.

Figure 2-5 The Boeing 787 Dreamliner

In 1977, over 30 years ago, the Boeing 727 fleet carried its one billionth (1,000,000,000) passenger, the first to be achieved by a commercial aircraft. Today the number is in excess of 4 billion. The 727 was the first best-selling airliner in the world when orders passed 1,000 in 1972, although the Boeing 737 has exceeded the final total orders for the 727 which ceased production in 1984 (Freeola, 2008b). The Boeing and Airbus fleets continue to dominate commercial aerospace manufacturing. Deliveries to March 2008 from Boeing (first was the Douglas DC-9 in 1969) number 16,713 (Boeing Website, 2008) and Airbus (first was the A300-B4 in1974) number

5,545 (EADS Airbus, 2008). Airbus has delivered more airliners per year than Boeing since 2003. Production levels reflect demand and economic circumstances, particularly the time-lagged dip following 9/11 in 2001.

Orders for aircraft for 2008 show that Airbus continues to maintain a lead in production with a net order book of 756, whilst Boeing's is 661 (Crump 2009). Despite this, only a small number of airliner models seating at least 100 passengers have been introduced over the last 50 years by what are now only a handful of organizations: Boeing (US), Airbus (Europe), Embraer (Brazil), Ilyushin and Tupolev (Russia) (see Table 2-1). Indeed because of the relatively small number of actual airliners delivered, we are able to identify the planes which continue in commercial use. For example, only 20 Concorde supersonic airliners were produced (Aerospace Web, 2004)and only 12 are still available to fly today, although the fleet was grounded in 2000 following the first Concorde accident in Paris, France in which a tyre blow out appeared to trigger a cascade of events killing over 100 people (Aviation Central, 2009).

Original organization	Organization today	Wide-body/ long-haul				Narrow-body/ medium-haul			
		Model	dates	number delivered	as at if still produced	Model	dates	number delivered	as at if still produced
United States & Canada									
Boeing	Boeing	747	1970 -	1409	30/09/2008	707	1958 - 1979	1010	
		767	1982 -	968	30/10/2008	717	1999 - 2006	156	
		777	1995 -	741	30/10/2008	737	1968 -	5857	30/09/2008
		787	2009 -	0	31/12/2008	757	1983 - 2004	1050	
Consolidated Vultee Aircraft Corporation	Boeing					Convair 880	1959 – 1962	65	
McDonnell Douglas & Douglas Aircraft Company	Boeing	DC-10	1971 – 1988	386		DC-9	1965- 1992	976	
		MD-11	1990 – 2000	200		MD-80	1980 – 1999	1191	
						MD-90	1995 – 2000	116	
Lockheed	Lockheed Martin	L-1011 TriStar	1972 – 1984	250		Constellation C-69/ Super Constellation C-121	1943- 1958	856	
South America									
Embraer (Brazil)	Embraer					E-jets: E-170, E-175, E-190, E-195	2002 -	446	30/09/2008
Europe									
Airbus	EADS	A300	1974 - 2007	561		A318	2003 -	65	30/09/2008
		A310	1983 - 2007	255		A319	1996 -	1126	30/09/2008
		A330, A340	1993 -	882	30/09/2008	A320	1988 -	2016	30/09/2008
		A350	2011 -	0	30/09/2008	A321	1994 -	483	30/09/2008
		A380	2007 -	22	31/12/2008				
British Aircraft Company (BAC) & British Aerospace	BAE Systems					BAC-111	1963 – 1989	244	
						Concorde	1976 - 2003	20	
						Bae-146/Avro RJ	1983 - 2003	387	
Fokker (Holland)	none					F100	1986 – 1997	283	
Vickers-Armstrongs	BAC					VC10	1962 - 1970	54	
Russia									
Ilyushin	Ilyushin	Il-86	1980 – 1994	106		Il-62	1967 – 1993	276	
		Il-96	1992 -	28	30/09/2008				
Tupolev	Tupolev					Tu-204/ Tu-215	1995 -	68	30/09/2008
						Tu-334	2009 -	0	30/09/2008
Totals									
				5808				16745	

Table 2-1 Airliner Models and Deliveries

By the third quarter of 2008, a total of 5,808 wide-body jetliners have been delivered, over 50% being Boeing planes. Three-times as many narrow-body or single aisle jetliners have been produced, at 16,745 a third of which are Boeing 737s. The jetliners which continue in production are easily identified in Table 2-1 as those with a date, the date indicating the numbers of jetliners manufactured as at that point.

Variants of commercial airliners sometimes exist for the transport of freight. Other adaptations include that for VIP corporate use, typically where the airliner contains fewer seats. A third variant is government use, where it is modified for different types of use, such as airborne tankers, air ambulance and reconnaissance, as well as troop carrying purposes. These variants are not of direct interest in this thesis however the versatility of many airliners has contributed to their longevity, for example, the Boeing 737.

Primes, that is those firms which produce airliners, are focused in the US and Europe. Some small amounts of production occur in Brazil and Russia. China planned to produce an airliner with 150 seats around 2010, but are first concentrating on smaller regional planes. China produced a large airliner, the "Yunshi", which had its maiden flight in 1980 but production was stopped as it failed to gain foothold (Asia Times, 2006).

2.2.2 Jetliner life cycles

It is relevant to note that the life-cycle of a particular airliner model is conceived years before it is operationalized. The life cycle of an aeroplane may be described as progressing through five phases as shown in Figure 2-6.

The first stage establishes the vision of the product and creates the design/concept using relevant current and anticipated technologies and innovations. At this stage, the previous relationships that an organization has developed are critical to gaining traction in strategic marketing of the product. Once the design is developed and has commitments from customers, the introduction of the product relies heavily on implementing the production of highly engineered modern products. Technologies and innovations are realised in the development of the product and the vision is refined. Long-standing supplier relationships are likely to be rewarded in terms of supplier selection. When in production, the focus is removed from product innovation to process innovation and the improvement of efficiencies in the manufacturing process. Increasing distribution and establishing the product more widely are key concerns for this stage of the product life cycle. Once mature and generating peak revenues, defending the market position of the product and remaining competitive become critical. Competitive cost and delivery adherence become paramount and so significant supply chain activity may occur, for example, as existing suppliers are replaced by low-cost economy suppliers. In the decline phase of the product, cost control becomes the imperative.

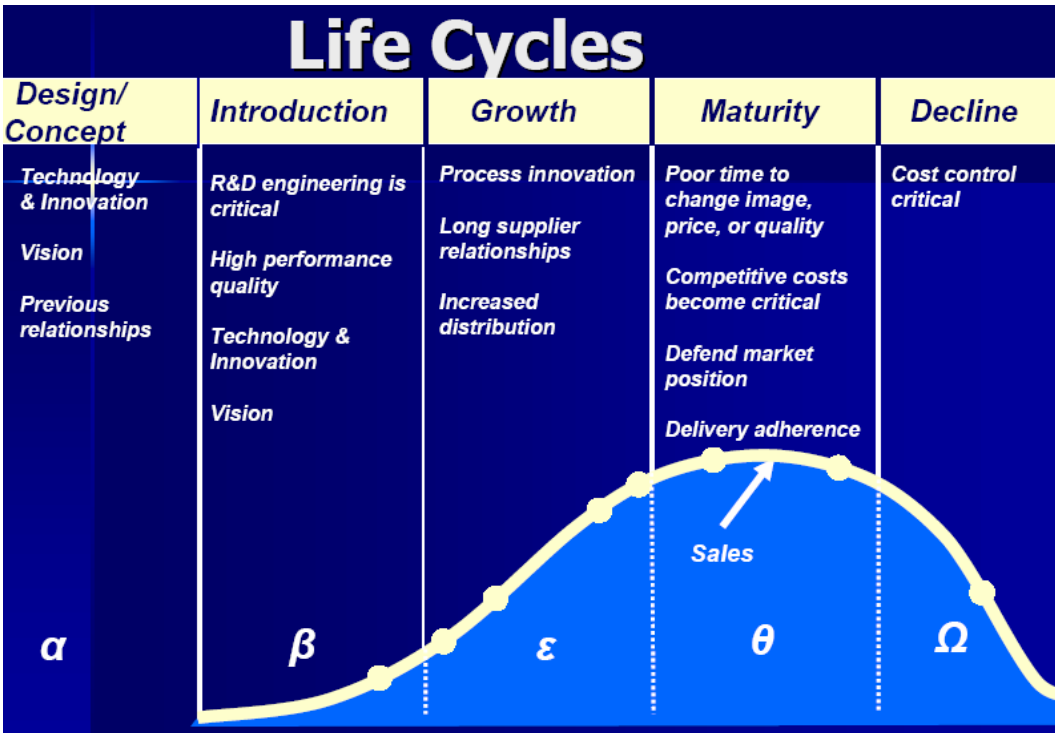


Figure 2-6 Product life cycle in aerospace industry (extended from Sheffield University model, based on Heizer and Render (2004))

The next section puts into context the amazing growth of airliners within the broader techno-economic environment and in particular considers the three generations of globalization.

2.3 The Broader Environment

This section looks at the broader environment of aerospace manufacturing in order to contextualize and historicize the research.

2.3.1 Global techno-economic paradigms

Three generations of globalization are used to describe the economic progress towards our current environment. Described variously as 'dominant logics of production/ techno-economic paradigms' (Tuomi, 2007), Schumpeter's waves (Schumpeter, 1942) or Kondratiev's macroeconomic cycles (Kondratiev, 1984), these describe the dominant or standard ways of economic development over different time periods. The nature of these globalizations or Schumpeter's waves, demonstrate new generic technologies driving renovation and innovation leading to new economic models through waves of creative destruction. These globalization paradigms are consolidated in Table 2-2.

The first globalization included four "logics" of production: water power, steam power, electricity; and oil. The earliest dominant "logic" was the harnessing of water power via canals in the period from the 1770s. This coincides with Schumpeter's 1st wave in which renovation was triggered by water power and the use of iron. The standard ways of working moved to mechanized methods.

The second dominant "logic" was steam power. This drove the investment in railways, increased the scale of production and the widespread use of steel which is described by Schumpeter's 2nd wave. Standardization of mechanical components was a feature of the increased production. Universal postal services and an emerging telegraph network were also characteristic of this era.

The third "logic" was the age of steel, electricity and heavy engineering from around 1875. Cheap steel was used to build ships, railways, bridges and tunnel. The wide use of electrical networks for lighting and industrial purposes completed these developments. Internal combustion engines and the start of the chemical industries typify this 3rd Schumpeter wave.

Dominant "logics" of production/ techno-economic paradigms	"Standard way of doing business," utilizing the new generic key technology	Schumpeter's waves
Canals and availability of water power, new infrastructures from 1770s	mechanized work	**Schumpeter I** renovation triggered by availability of waterpower and use of iron
Steam and railways; universal postal service and the emergence of telegraph networks	increased scale of production, which in turn was based on standardization of mechanical components; increased use of telegraph	**Schumpeter II** use of steam, the production and wide use of steel
Age of Steel, Electricity and Heavy Engineering, starting from 1875	cheap steel, which, among other applications, was used to build steam-engine based steel ships, worldwide railways, electrical networks for illumination and industrial use, as well as bridges and tunnels that complemented the new transport technologies	**Schumpeter III** wide use of the electricity; development of internal-combustion engines; start of chemical industries from 1900s
Age of Oil, Automobile and Mass Production from 20th century End of 1st globalization	associated with key new technologies such as the automobile, electricity and the availability of cheap oil, the standardization of products, utilization of scale benefits, realization of the emerging economic potential required the development of infrastructures such as highway networks, airports, oil ducts, and worldwide telecommunications; Mid 1960s – international telephony	**Schumpeter IV** rise of petrochemical products from oil and gas; development of electronics and aviation industries
Age of Information & Telecommunications (or the Information Society) 2nd globalization	since the invention of semiconductors and general-purpose microprocessors, the economic system has increasingly been organized around efficient use of information and communication technologies; exchange of documents with rich content in early 1990s; direct dialing and email messaging	**Schumpeter V** growth of digital networks, software and the new media
3rd globalization	Broadband communications network, global division of labour; internet-based business models, real-time virtual service	

Table 2-2 Globalization paradigms adapted from Tuomi (2007) and Schumpeter (1942)

The fourth "logic" was the age of oil and the new technologies of the 20th century such as automobile production. Products became standardized and scale benefits were extracted as functionally diversified and hierarchical organizations appeared. Investment in infrastructure such as highways, airports, oil ducts and worldwide telecommunications was typical in the West. The rise of petrochemical products from oil and gas, the development of electronics and aviation industries characterizes Schumpeter's 4th wave. After 1940s, jet airplanes enabled managers to travel regularly to distant plants.

The 2nd globalization is known as the age of Information Technology or the Information Society. The invention of semi-conductors and general purpose microprocessors has shifted the economic system to the use of information, enabling the exchange of rich content via direct dialing and email messaging. This is the start of Schumpeter's 5th wave which highlights the growth in digital networks and software.

The 3rd globalization sees a rise in broadband communications, with internet based business models which can provide a real-time virtual service. Labour is divided globally. We are now in the 3rd globalization or Schumpeter's Vth wave, defined by broadband communications networks, global division of labour, internet-based business models and real-time virtual service. Continued miniaturization is enabling the end-customer to perceive an increasing value during flights with the accessibility of increased multi-media technologies.

Schumpeter's Waves printed in The Economist (Valery, 1999) (see Figure 2-7) show how the macro-economic and price cycles of roughly 50 years, are firstly, contracting and secondly are regular. Schumpeter's 5th wave is expected to be of some 30 years duration, whilst the 1st was some 60 years showing a contraction over time. The regularity of each cycle is one of a period of prosperity, one of recession, one of depression and finally one of improvement. If the illustration is accurate, 2010 will be the tail end of a period of prosperity. This may have been precipitated in 2008 with the global financial crisis, bringing this 5th wave to a premature period of recession.

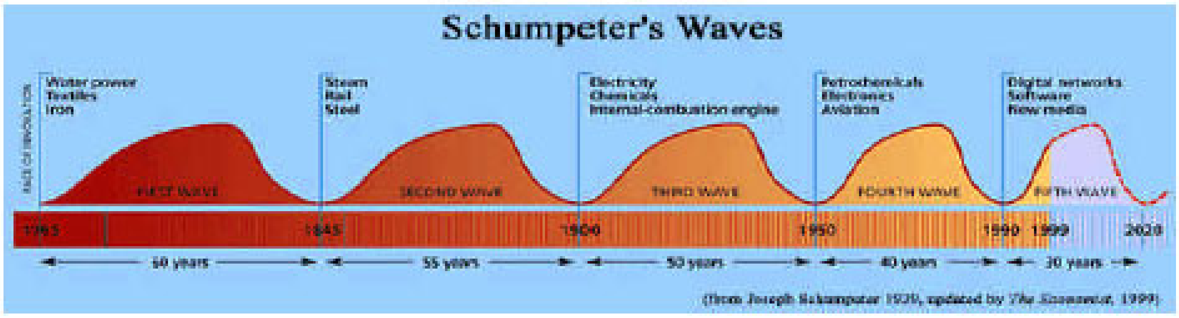


Figure 2-7 Schumpeter's Waves (Valery, 1999)

These eras or waves of new all-purpose technologies drive investment in the development of new infrastructure leading to new economic models through waves of creative destruction. Schumpeter (1942) tells us that the roots of economic growth (or crisis) are in technological innovation.

2.3.2 Innovation

Patterns of innovation developed from empirical evidence show that innovation is not linear and has a coevolutionary effect on the population of organizations, the emergent organizational forms and their likelihood of imitation. Dominant Design Theory (Abernathy and Utterback, 1978) holds that innovation is altered significantly once a dominant design of technology emerges. This describes a paradigm shift. For example, within the 1st globalization (see Table 2-2) the innovations related to the new dominant technology design, such as those related to steel, supersede previous dominant designs. The dominant design may reduce and even eliminate further innovation activity and the fitness of competing product technologies in the old paradigm but will increase the innovation activity associated with the dominant design (McCarthy, 2003).

The rate of innovation within a dominant design or paradigm appears to follows a logistics growth curve. Technology S-Curve Theory (Christensen, 1992) proposes that performance improvements of innovations follow the shape of an S-curve. As performance improvement declines, resources should be diverted to exploration of the next innovation. Technology and Market Trajectories Theory considers the intersecting trajectories of market demand for performance and performance delivered by the technology (Dosi, 1982). A potentially disruptive technology or innovation

(Christensen, 1992) may perform inadequately early on but it can be significantly disruptive when its trajectory meets market demand for performance. This in turn has a significant effect on the organizations in the population affected by the innovation.

If we consider the landscape of all firms, then the tallest or highest performing ones grow less quickly. Kauffman (1995a: 177) states that a fundamental property of very many rugged fitness landscapes is that the *"rate of improvement slows exponentially as one clambers uphill"*. He puts this down to conflicting constraints whereby both biological evolution and technological evolution are processes attempting to optimize systems. This reflects the phenomena that learning is more modest and scarce for success trials and displays the "Red Queen Effect", from Alice in Wonderland, showing the need to run faster and faster just to stay at the same pace (Barnett and Hansen, 1996).

Evolutionary processes that unfold in characteristic patterns appear in Schumpeter (1942) as waves of Creative Destruction. Markets have periods of comparative quiet, when firms have developed superior products, technologies or organizational capabilities which earn positive economic profits. Quiet periods are punctuated by shocks or discontinuities that destroy old sources of advantage and replace them with new ones. These are phase transitions and replace 'gradualist evolution' with punctuated equilibrium (Eldredge and Gould, 1972). Entrepreneurs who exploit the shocks create positive profits in the next period of quiet.

It is the firms in the environment which innovate and thus create the technological trajectories of the environment. Firms thus co-evolve with the environment. The success of individual firms will be related to the compatibility of the firm to the technological trajectory of the extant paradigm. Technological breakthroughs may enhance or destroy competencies in firms (Tushman and Anderson, 1986). Competence-destroying discontinuities are created in new firms and increase environmental uncertainty and turbulence. However, competence-enhancing discontinuities are created in existing firms and increase environmental stability. Innovation and the outcomes of innovation, such as new products, processes and techniques, shape the characteristics of organizations, new and old but managers are heavily constrained in their technological search by complexity and path-dependency (Patel and Pavitt, 1997).

2.3.3 Growth and competition

The perception of "technological paradigms" as "science push" models of innovation are being displaced by "demand pull" models that justify a more international, market-focused political economy. Technological paradigms help explain the strengths and weaknesses of both models and why governance choice is not between either markets or governments, but an appropriate mixture of both, in which the focus is building stocks of knowledge (von Tunzelmann et al., 2008).

In his study of the patterns of competitive success in ten leading trading countries, Porter (1990) concludes that acts of innovation create competitive advantage. The national environment as described by Porter's diamond of national advantage, affects the capacity and push to innovate within a national context, helping to achieve international leadership.

But not all industrial sectors have the same patterns of innovation. Pavitt's (1984) technological trajectories identify three classes of firm: supplier-dominated, production intensive and science-based. The proposed taxonomy is explained by sources of technology, requirements of users and possibilities for appropriation. The determinants of innovation also have moderating conditions, such as firm size, industrial sector and country environment (Wolfe, 1994) and recognized environmental contexts, for example, Emery and Trist's (1965) environmental textures each characterised by different adaptive responses.

Thus the environment is dynamic with periods of stasis, periods of incremental change and periods punctuated by technological breakthroughs. Firms initiating major technological changes grow more rapidly than other firms.

Representing ten years of research into the history of the managerial business system, Chandler Junior (1990) describes patterns of growth and competitiveness in the U.S., Germany, and Great Britain since 1870s. The evolution of the 200 largest multinational giants is explored, orienting the late twentieth century's most important developments. Chandler shows that successful firms implemented strategies which shaped markets. They did not just accept the technological environment and the markets to which they belonged. Three types of capitalism are identified: in the USA it is competitive managerial capitalism; in the UK it is personal capitalism and in Germany, it is cooperative managerial capitalism. The difference between Germany and the USA was the attitude of respective governments to industrial collusion. In the USA anti-trust laws prevented partnerships on order to prevent collusion whereas in Germany the law gave active support to the establishment of industrial cartels. However, goals in the USA and Germany are similar and related to long-term profit and growth of the firm whilst in the UK, goals were a steady flow of cash to the family-owned and personally managed firms, constraining the growth of the firm by limiting the profits available for investment.

Ormerod (1994) extends Chandler's work suggesting that the traditional goals of USA firms have changed to a short-term focus, damaging the long-term capability of the USA economy. Germany, has maintained a long-term growth and long-term profit focus. In Japan, which is not within the scope of Chandler's work, Ormerod argues that a new general dimension of industrial capitalism has emerged. This is based in micro-electronics and information technology which are driving flexibility of production, smaller volumes of production and increased diversification. However, even in Japan, the ingredients of corporate success lie in investment and a long-term focus, sustained by a good cash flow from operations or from long-term relationships with the financial sector. This focus on flexibility, demands a close relationship with efficient suppliers and distributors.

2.3.4 Summary

In this section, the broader environment, macro-economic cycles and technological regimes have been discussed, demonstrating the waves of creative destruction within which the commercial aerospace industry is situated. The role of innovation and competition in the context of macro growth is touched upon. The next section considers the proximate influences of the environment on airliner design and production.

2.4 Environmental Influences in Jetliner Production

Five types of environmental influences are evident in the history of jetliner production: global connectedness, technology know-how, customer expectations (for quality, cost, security), competition and ‘sustainability, regulations and legislation’. The following sections discuss some examples of these major changes.

2.4.1 Global Connectedness

Recent changes implemented in Toulouse, the European capital of the commercial aerospace industry, are used to describe the transition from a national-regional logic to a global-local one (Longhi, 2005). This transition and the dynamics of globalization of the contemporaneous economies are described using three dimensions: technology management, organisation and territories.

The increasing use of information communication technologies (ICT) is uniting global networks across different time periods, enabling the sharing of information and the use of previously untapped resources in the development, production and servicing of aircraft (Ho et al., 2003).

2.4.2 Technological know-how

The dominant technologies in jetliner production are the jet engine and composite materials. Information technologies, such as RFID, are also coming into use.

One of the first enabling technologies for aircraft accelerating the growth of commercial air services was a technological innovation in flight de-icing systems. After his first solo non-stop transatlantic flight in 1927, Charles Lindbergh identified that ice was the greatest danger during the trip. Goodrich produced the first aircraft de-icing systems and is an innovation which Goodrich continues to lead today (Goodrich, 2009).

Composite materials are the most important materials adapted for aviation use since aluminium in the 1920s (US Centennial of Flight Commission, 2004). Dr Leo Windecker began experimentation with composite materials in 1956. It was not until 1969 when the FAA (Federal Aviation Administration) certified the first composite materials plane – the Windecker Eagle AC-7 (Aero Files, 2008). Collaborative knowledge sharing in the recent developments in composite materials show the value of out of sector knowledge for aerospace (McAdam et al., 2008),

Composites are advantageous due to their light weight, which aids fuel consumption, and their strength. However they are more complex to manufacture than most metal structures and are difficult to repair and fault detection is challenging. Composites are materials formed from a combination of two or more components, one material serving as a matrix, holding everything together, and the other serving as reinforcement in the form of fibres embedded in the matrix. The most common matrix materials have been "thermosetting" materials such as epoxy, bismaleimide, or polyimide; reinforcing materials have been glass fibre, boron fibre, carbon fibre, or other more exotic mixtures (US Centennial of Flight Commission, 2004; Mazumdar, 2001). Fibreglass is the most common composite first used as 2% of the structure of the Boeing 707 in the 1950s. In the recent A380, composites form 25% of the airframe by weight, including the central wing box although the fuselage is aluminium.

The jet engine was the technology which enabled the creation of jetliners. Modern jetliners are powered by turbine engines which operate efficiently at much higher altitudes and with greater reliability, than piston engines. They also produce less vibration and noise. Many second generation jetliners such as the BAC-111, Boeing 727 and Tupolev Tu-154, used a rear-engine T-tail configuration (Absolute Astronomy, 2009). Whilst this configuration is still used on some short and medium haul planes, design of airliners has converged to a low-wing design w(US Centennial of Flight Commission, 2004)ith engines mounted in under-wing pods. Access is quicker and easier for maintenance compared to tail-mounted engines and it enables a lighter wing structure.

The market for RFID (Radio Frequency IDentification) solutions deployed by aerospace and defence companies is expected to exceed $2billion by 2011 (Mobile Radio Technology, 2006). RFID is a technology which provides the automatic identification of specific products, enabling them to be tracked and monitored. Rolls Royce, a first tier OEM (Own Equipment Manufacturer) and engine solutions provider, began its trial of RFID in 2006 with adoption in 2007 within the US Department of Defense. The adoption in commercial aerospace would follow over time (Hadfield, 2006).

2.4.3 Customer expectations

At the start of the 21st century, the severe knocks to the global commercial aerospace industry following 9/11, SARS (World Health Organization, 2009) and the Iraq war caused industry lay-offs and consolidation as customer demand for air travel waned. Terrorism acts such as 9/11 create incredible shocks to aircraft orders and if supply chains are unable to adapt, e.g. from commercial to defence production, then supply chains will not be able to compete or survive.

Arguably, the success of jetliner models and organizations has depended on the severity and frequency of accidents. Nearly all jetliner accidents make the news for the very reason that they transport the public. Accidents with fatalities are reported (see for example Airsafe (2008)) giving details of crash events and crash rates based on number of flights. Safety and the role of the civil aviation authority of each nation in maintaining safety standards during civilian flight are critical to customer confidence in selecting flight travel. The role of the civil aviation authority of each country is to ensure safety standards and to have the power to ground airliner models. A safety feature, for example, is multi-engine design which is mandated by some national regulations in order to allow airliners to climb, even in the worst case scenario of power loss in an engine after take-off. Multi-engine design also meets another regulatory demand that allows airliners to fly a minimum specified amount of time after an in-flight engine failure. The highest quality of jetliner products are demanded from customers in order to ensure their personal safety during transit.

Air traffic has now fully recovered from the impacts of 9-11. North American and European airports are facing increased demand and urgent need for expansion of runways and terminals but this is being resisted largely as a result of environmental opposition. Dramatic economic growth and increased aviation demand has been achieved in emerging market countries. In China, this growth is led by government investment and economic partnerships in manufacturing and exports. In India, public-private partnerships, government liberalization and high-technology industries drive the growth. In the Middle East, government investment in infrastructure is funded by oil and gas revenues. Each of these emerging areas are able to respond aggressively to demand, building airport facilities quickly on a massive scale. These changes are shifting the future of aviation from West to East (Assa and Denton-Brown, 2008).

Social and economic benefits of air transport, including improved international cooperation and increased consumer choice are persistent drivers increasing demand. Yet other social changes, such as the growth in obesity due to energy dense food, motorised transport and sedentary lifestyles (Foresight, 2007) will create demand to carry larger people reducing the number of seats on a jetliner.

The flying speed of airliners appears not to have progressed since the production of the commercial airlines in the 1960s which flew at around 80% Mach. The latest Boeing 787 has maximum cruising speed of Mach 0.89 and range of 14,200 – 15,200 km. Similarly the Airbus 380 has the same maximum cruising speed with a range of 15,200 km. These performances compare with for example the Boeing 747 from 40 years ago and indeed have not improved much since the 1960s (McDonnell, 1985). The adoption of super-sonic jets such as Concorde for everyday passenger travel has failed to become a reality. Thus travel time is largely unchanged.

2.4.4 Competition

Government protectionism may be observed in two ways. Statutory instruments or laws are sometimes created, supporting industry restructuring and consolidation, enabling firms to compete globally, but also preventing product sales, and loss of intellectual property rights, to other nations. Governments have also awarded contracts to local firms, rather than sought to achieve best value, although this approach tends now to be more related to defence contracts. Historically, national prestige was attached to developing airliners and bringing first generation designs into service. There was also a strong nationalism in purchasing policy. In 2008, we find Boeing's bid for a U.S. Air Force contract has been won by a non-U.S. based consortium. Nationalism was overcome by global competition despite Boeing's reliance on global networks to complete its contracts (Epstein and Crown, 2008).

Further evidence of global competition can be seen in the opening up of competition, following the Civil Aviation Authority (CAA) proposed reductions to the returns chargeable by BAA (owner of Heathrow, Stansted and Gatwick) which should result in lower charges and improved service, via increased competition.

Industry consolidation and tiering (reduction in direct suppliers) is likely to take place in the UK and increased sourcing from low cost economies is predicted (DTI Aerospace and Defence Directorate, 2003). Accelerated global outsourcing, punishing competitors and supply/demand mismatches will create major disruption in supply chains (Lawrie et al., 2003). The location of developing skills and knowledge, particularly in great numbers in China and Russia will be a source of competition for the west.

2.4.5 Sustainability, regulations and legislation

Despite growing demand for flight, enabling international cooperation, social mobility, overseas holidays, etc. the effects of flight continue to influence the industry. The need to reduce CO_2 emissions and its effects on global warming have become global political issues but remedies to reduce emissions appear to have a negative effect as world-wide demand for air service including freight transport which is expected to double by 2010 (Air Transport Action Group, 2008). Political interventions include carbon-offsetting; proposed restrictions on airport growth and routes; rising air passenger duty and alternatives such as EasyJet's proposals for a flight tax (Millward, 2007) which penalises older environmentally unfriendly planes and those with low passenger numbers (but still creates UK treasury revenue of around £2.4bn per annum) . Other environmental concerns range from aircraft noise, to fuel consumption and the need for energy efficiency, improved infrastructure and land use. ICT is also providing a substitute to some forms of travel, e.g. by enabling multi-media conferencing over IP (internet protocol).

Compliance is required by firms with a range of environmental legislation (SBAC, 2009). Legislation in the form of "The Civil Aviation Act" implements, amongst other things, commitments to sustainable aviation and protection of passenger interests defined in the Future of Air Transport White Paper (Department for Transport, 2005).

Air pollution and toxic waste monitoring and intervention continue to dominate the agendas of environmental protection agencies. The airline industry is responsible for about 11 percent of greenhouse gases emitted by the U.S. transportation sector. Boeing estimates that biofuels could reduce flight-related greenhouse-gas emissions by 60 to 80 percent by blending algae fuels with existing jet fuel (González, 2007). Informal collaboration between Boeing and leading biofuels makers in for example in Brazil and New Zealand, is testing biofuel options for aviation.

The primes have programmes of investigations which are focused on improved product efficiency. Four concept designs were being examined by Boeing (Gates, 2006) codenamed after the well-known Muppets. All four design designs have rear-engine layouts and concentrate on reducing fuel usage. Two of the concept planes concentrate on low emissions and low noise.

The major challenge facing the aviation industry is sustaining growth which meets the needs of modern society and also safeguards the environment for future generations. Despite demonstrable efficiency and environmental achievement, the industry cannot meet this challenge alone (SBAC, 2001).

The Sustainable Aviation initiative is aimed at laying out a credible and detailed way for the sector to address legitimate environmental concerns. Signatories to the initiative are drawn from the airlines, airports and manufacturers, along with air navigation services provider NATS. The umbrella structure hopes to develop and support commercial aviation in making its collective case to government and the public (Barrie, 2008).

2.5 Trends

The industry was expected to recover historic rates of demand in 2005 and indeed to grow at a rate of 4.7% per annum to 2022 (AIGT (Aerospace Innovation and Growth Team, DTI), 2003), valuing the global industry at $1,860 billion over 20 years relating to some 32,500 new aircraft. This anticipated growth is expected to contribute to a set of key characteristics (AIGT (Aerospace Innovation and Growth Team, DTI), 2003) that would define the global commercial market by 2022:

1. airline industry restructuring;
2. improved environmental performance and highly efficient aircraft structures and fuel consumption;
3. sophisticated security measures;
4. improved business models for manufacturers and service providers;
5. serviced-based, total life cycles packages to commercial aerospace customers.

In addition, aerospace primes and systems integrators are expected to achieve better rewards attracting more private capital. 2 to 4 above are directly concerned with either airliner re-design or economic model re-design, within the scope of aerospace primes; whereas 1 and 5 above are airline and financing related. 3 is also airport based.

Overall trends for the aerospace industry (AIGT (Aerospace Innovation and Growth Team, DTI), 2003) are

- the fusion of manufacturing, service provision and MRO (maintenance, repair and overhaul);
- a change to the concept of 'prime contractor' being the aircraft manufacturer to it being an aerospace service provider, whose capability may be solely the "conception and management of large scale systems";
- greater technology sharing with military products and other sectors;
- growth in the systems concept of commercial aerospace as a global, integrated air transport system;
- globalisation and less nationalism.

Within the last 10 years as a consequence of globalization and proliferation of multi-national companies, strategic alliances, joint ventures and other forms of partnerships, have been found to contribute to the success of supply chain performance, just as Just-in-Time, Lean, Agile and similar manufacturing practices (for example, Womack (2002) and Gunasekaran (1998)). The rise of the information age and greatly reduced information communication costs is changing coordination mechanisms among partners in the supply network (Coase, 1998), increasing collaborative work within teams on high capacity networks (Tapscott, 1996), enabling continuous information flow in an integrated supply network (Lambert and Cooper, 2000) and providing new opportunities for customers to connect to supplier and to reduce transaction costs and risks (Lewis and Talalayevsky, 2004). Supply chain integration of legally and spatially separated firms is shown as a vital tool for competitive advantage (Yusuf et al., 2004).

In response to changing industry conditions and global economic challenges, changes in the UK aerospace industry reflect the adoption of better, faster and more affordable products (Grant, 2005). To meet the emerging challenges of the twenty-first century, the global aerospace industry needs to transform the roles and working relationships of its many participants by focusing more on core competencies, accelerating outsourcing trends, increasing industry-wide collaboration and embracing more "best value" providers from outside the industry, thereby providing truly end-to-end customer solutions (AIGT (Aerospace Innovation and Growth Team, DTI), 2003).

Aerospace industry trends (DTI Aerospace and Defence Directorate, 2003) have reported that industry consolidation and tiering is likely to take place in the UK and increased sourcing from low cost economies is predicted, as follows:

- radical reduction in direct suppliers and a rationalization of supply networks;
- greater differentiation between suppliers, thus more specialisms;
- primes to focus on systems integration and assembly;
- technical and financial risks and supply chain management will pass to 1st tier suppliers;
- over capacity in fabrication and component sectors could result in the failure of many smaller manufacturers;
- UK suppliers will not be able to compete against China and Korea for low-value labour-intensive manufacturing work;
- aerospace manufacturing is being captured by the Far East and Japan, for example, based on lean processing, so smaller aerospace companies may not survive.

2.6 Discussion

A number of environmental trends from macro-economic cycles, industry trends and globalization effects appear to have an impact on the commercial aerospace industry. The discussion of trends in the industry have begun to introduce the notion of global, integrated supply networks.

Changes in the nature of the firm have arguably been more profound in the last 50 years than at any earlier time in history. It is argued in this thesis that changes in the firm have occurred as a consequence of three exogenous (in the economic sense) factors:

- The fast evolving environment of the firm, including the availability of new materials, technologies, methods
- The growing ability of firms to create and adopt variations of inter-organizational structures and governance mechanisms, including the physical distribution of sites and plants
- The increasing maturity of inter-organizational practices and relationships in the supply network, including competitors, suppliers, professional and industrial organizations

It is also argued that these factors are coevolutionary with the firm. If a firm adopts (or declines) an aspect of its changing environment, it has an effect not only on the firm but on the environment stimulating (or dulling) that aspect of the environment's evolution. Similarly, the performance of various structures and governance mechanisms in the supply network can be more or less effective at different times. New variations and the speed with which they can be constituted can create novel performance outcomes within the particular space and time of the supply network. Finally, as inter-organizational practices evolve, absorbing or consolidating earlier versions of practices, evolution occurs in these practices affecting industry practice.

2.7 Summary

This chapter has introduced the environment of the commercial aerospace manufacturing of jetliners. It has identified the products of the industry (see Table 2-1) and has described the characteristics of the environment:

- Global Connectedness
- Technological know-how
- Customer expectations (for security, quality, etc)
- Competition
- Sustainability, regulations and legislation

Future trends were established and discussed

- rationalization;
- specialisation;
- primes to focus on systems integration and assembly;
- 1st tier to take on risks and supply chain management
- reduction in smaller local manufacturers;
- increase in far-east labour-intensive manufacturing work;

This chapter has identified environmental characteristics as set out in Chapter 1, Q1a: "*What are the characteristics of the environment*?"

The next chapter presents the literature review of firm and supply network coevolution.

3 FIRM AND SUPPLY NETWORK LITERATURE

"As evolutionary theories explore processes that engender the innovation of new organizational forms, new insight will be gained regarding the role of organizational change and inertia."

(Romanelli, 1991: 99)

3.1 Introduction

This chapter forms the literature review of firm and supply network coevolution. The scope of the literature review is wider than commercial aerospace manufacturing as extant literature is rarely focused on specific industrial sectors, rather it is generalized with examples in substantiation from a variety of markets and sectors.

Further ambiguity exists in the literature as a result of the use of the word 'organization', sometimes referring to the firm, sometimes the firm and its suppliers, sometimes the entire supply chain, sometimes including customers and the demand chain. This thesis avoids the use of the word organization, except where it refers to the process of organizing. Firm is used to describe the legal entity which trades and produces goods and services. Supply Network is used to describe the entire network of relationships and inter-connections between firms enabling the design, production and delivery of goods, services and information that are required to produce the jetliners.

This chapter is organized into a number of sections which consider the evolution of the firm, the evolution of the supply network and inter-firm characteristics. Firm and supply network archetypes are exposed as are the dynamics involved in their evolution. The final sections identify inter-firm characteristics and the expected performance success criteria of supply network membership which inform the empirical research study. Specific research gaps identified in the literature are presented.

3.2 The Evolution of the Firm

Organization Theory, the umbrella term uniting theories, frameworks, metaphors and so on for explaining and understanding change in socio-economic groups, is rich with different perspectives, paradigms and terminology. This section therefore aims to focus on those literatures which discuss the evolution of the firm. There are two aspects to this. First is the way in which similar firms are described, that is the classification mechanisms of firms, be they organizational forms and so proximate to practice, or conceptual archetypes or typologies. Second is the coevolutionary dynamics of firms which covers the inter-firm practices, methods, relationships and so on that create a dynamic and trigger mutual adaptation between the firms and the supply network.

3.2.1 Organizational typologies

If we consider that a firm is constituted by its employees (and their skills and knowledge), the products and services delivered, the assets employed and so on, then we can say that firms are idiosyncratic; no two firms are identical. When we find similarities and differences between instances of firms, we find ways to compare firms in an abstract way. The typologies or ideal types that we create in our theorising do not exist as firms; they exist to help describe, simplify, and sometimes explain, why and how certain types of firm function, perform or change.

Typologies have long been used for classification (Rothschild-Whitt, 1979; Bailey, 1994). Some of the earliest typologies are widely known in management research and practice:

- Feudalist and Capitalist (Marx, 1976);
- traditional; rational-legal and charismatic (authority) (Weber, 1958);
- Mechanistic and Organic (Burns and Stalker, 1994);
- Generalist and Specialist (Hannan and Freeman, 1977; Aldrich, 1979);
- Prospectors, Defenders and Analyzers (Miles and Snow, 1978);
- Simple Structure, Machine Bureaucracy, Professional Bureaucracy, Divisionalized Form and Adhocracy (Mintzberg, 1980);

- Cost Leadership, Differentiation, Market Segment focus (competitive strategies) (Porter, 1980);
- Operating organizations and innovating organizations (Galbraith, 1982).

Consistent across all these typologies is the inherent risk of mortality for firms attached to changing from one cell of a typology to another (Rothschild-Whitt, 1979).

3.2.2 Organizational forms

At this time in the late 1970s when many typologies were described, McKelvey (1975; 1978) called for a scheme in order to improve confidence regarding the generalisability of research findings for the benefit of functional studies, organization design and development and management practice. McKelvey devised Organizational Systematics, the science of diversity, as having three components:

- Taxonomy – a theory of differences among organizational forms plus a theory of classification.
- Evolution – the tracing of the historical origin of different lineages, to show how organizational forms have evolved and what groupings have emerged.
- Classification – the identification and assignment of organizational forms to formally recognised classes.

Critically, McKelvey connected practice with classification. Conceptual typologies are often constructed along dimensions or factors which themselves create types that do not appear in practice. The Organizational Systematics approach overcomes this by permitting greater diversity along evolutionary branches of the tree and placing firms within the nodes that are recognised as specific classes of firm. Taxonomy is similar to typology in that objects within the classification belong to only one taxa or type respectively. This means that both techniques are monothetic - a case or object must be identical on all variables or characters measured. Often these variables are dichotomous or binary in that they have only two states or values.

The concept that a firm has an evolutionary history is also used in the notion of organizational *routines* described by Nelson and Winter (1982). Routines act as repositories of knowledge explaining how the firm can do different things. These routines thus act as genes and need continual reproduction.

Hannan and Freeman (1977), on the contrary, proposed no fixed rules or typology insisting that classification of a firm as one form or another may be according to the needs of the investigator; there is no single correct classification. Others gave priority to the dimensions of variation, i.e. the identification of the elements that would enable a taxonomy to be defined, for example Technology, Coordination and Control (Aldrich and Mueller, 1982); Organizational Culture, Strategy, Structure, Power Distribution and Control Systems (Tushman and Romanelli, 1985) and Goals, Social Structure, Technology, Participants, Environment (Scott, 2002).

The alternative conception of design archetypes encompassed both structural form and patterns of behaviour (Greenwood and Hinings, 1988). Three reasons are found for alternative design archetypes: (1) contingencies (for example, size, environment) where inertia is a consequence of little contradiction between contingent circumstances and design arrangements; (2) power dependencies, in which particular organization designs serve the interests of some groups better than others, so the extent to which other groups are dissatisfied and able to express or protect their interest in the design, will affect the desire to change; (3) interpretive schemes, or culture, and the levels of commitment to current or alternative schemes. Design archetypes considered the system and its dynamic and so attempted to solve the issue of transformation from one archetype to another. Weaknesses of design archetypes are its basis in functionalism (Kirkpatrick and Ackroyd, 2003) and its lack of focus on boundaries (Wolstenholme, 2003).

Romanelli (1991) noted that theoretical perspectives varied widely on the appropriate approach to the creation of taxonomies that describe organizational forms. She states: "*the concept of organizational form refers to those characteristics of an organization that identify it as a distinct entity and, at the same time, classify it as a member of a group of similar organizations*" (Romanelli, 1991: 82).

3.2.3 Cladistics

The notion of an evolutionary classification of organizational forms has been progressed over recent years by methods that enable visualisation of taxonomic evolution. This visualisation aids the understanding of the history of organizational form development and the concept of distance and variety between different types of organizational form.

Cladistics, is a method of mapping phyletic relationships based on recent common ancestry (Bailey, 1994). McCarthy (1995) considered how Cladistics, used mainly in biology, had a usefulness in organizational taxonomic definition. The Cladistics method was used for research in the automotive manufacturing sector (McCarthy et al., 1997b). It showed the occurrence of successive new practices and innovative ideas in the manufacturing sector and how they translated into the observed organizational forms of the industrial sector. The research identified 53 constituent characteristic practices (see Figure 3-1) and 16 organizational forms (bundles of these characteristics) that had been observed since the beginning of the industry. Each organizational form represents a unique set of particular capabilities and operational abilities. The analysis of these structures allowed the construction of a cladistic diagram for automotive assembly plants, showing the major branching points when qualitatively different capabilities emerged. Figure 3-2 defines the organizational forms that are found in practice. Note the key bifurcation that occurred when organizations became either lean manufacturers or mass producers.

1. Standardisation of parts
2. Assembly time standards
3. Assembly line layout
4. Reduction of craft skills
5. Automation (machine paced shop)
6. Pull production system
7. Reduction of lot size
8. Pull procurement
9. Operator based machine maintenance
10. Quality circles
11. Employee innovation prizes
12. Job rotation
13. Large volume production
14. Suppliers selected primarily on price
15. Exchange of workers with suppliers
16. Socialisation training (master/apprentice learning)
17. Proactive training programs
18. Product range reduction
19. Automation
20. Multiple sub-contracting
21. Quality systems (tools, procedures, ISO9000)
22. Quality philosophy (TQM, way of working, culture)
23. Open book policy with suppliers; sharing of cost
24. Flexible multi-functional workforce
25. Set-up time reduction
26. Kaizen change management
27. TQM sourcing, suppliers selected on basis of quality
28. 100% inspection/sampling
29. U-shape layout
30. Preventive maintenance
31. Individual error correction; products are not re-routed to a special fixing station
32. Sequential dependency of workers
33. Line balancing
34. Team policy (motivation, pay and autonomy for team)
35. Toyota verification of assembly line (TVAL)
36. Groups vs teams
37. Job enrichment
38. Manufacturing cells'
39. Concurrent engineering
40. ABC costing
41. Excess capacity
42. Flexible automation for product versions
43. Agile automation for different products
44. Insourcing
45. Immigrant workforce
46. Dedicated automation
47. Division of labour
48. Employees are system tools and simply operate machines
49. Employees are system developers; if motivated and managed they can solve problems and create value
50. Product focus
51. Parallel processing
52. Dependence on written rules; unwillingness to challenge rules as the economic order quantity
53. Further intensification of labour; employees are considered part of the machine and will be replaced by a machine if possible

Figure 3-1 Automobile Manufacturing Characteristics (McCarthy, Leseure et al, 1997)

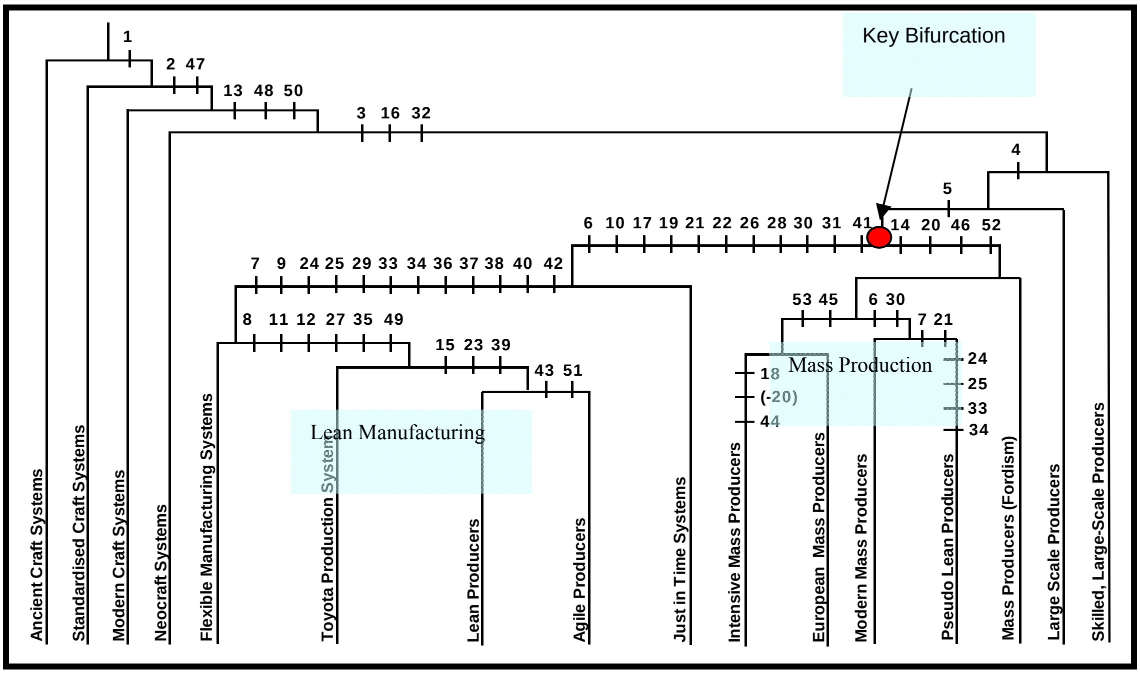


Figure 3-2 Automotive Manufacturing Cladogram and Organizational Forms (McCarthy, Leseure et al, 1997)

Leseure (2002) charts the history of Cladistics and identifies its benefits as a method for historiography, an effective combination of analysis and synthesis and a support tool for collective modelling. The Cladistics approach to classification together with q-analysis (a method from algebraic topology) has been applied to strategic management and change as useful tools to identify different configurations, relationships, and change routes between current and desired configurations (Rakotobe-Joel et al., 2002).

Under the ESRC NEXSUS project (Allen, 2004) a survey of 73 manufacturers' views of how the 53 characteristic practices interact with each other was carried out. A matrix of the interactions between each pair of the 53x53 practices was constructed, quantifying the degree of synergy or conflict between them. Two practices are mutually "helpful" and reinforce each other and so have synergy, or on the contrary, they are mutually exclusive and conflict with each other. The successful inclusion of any new practice in a particular organization is related to its degree of synergy (complementarity or coherence) with those practices already present. This leads to a view in which successful organizational forms are found to be those whose constituent practices are internally coherent (Allen, 2001b).

This allows us to understand the relationship between the "identity" of a firm as described by the interaction of its internal constituents and its emergent capabilities and attributes. This indicates to some degree which innovations and new practices will be most suitable for which companies. Further, the health of the overall system is dependent on the extent of synergy between such interacting characteristics (Allen, 1994). More recently, the evolutionary perspective has been used in organization change, in which a process approach is advocated (rather than the use of variables) which is contextualized in chronology (Poole et al., 2000).

This sub-section looked at the classification of organizations. Archetypes represent conceptual typologies and have been used widely in organization science. The notion of organizational forms connects classification to taxonomy and empirical forms. When used with phyletics it identifies historic lineages whereby particular characteristics have been acquired or emerged over time. The next sub-section looks at the importance and relevance of coevolutionary dynamics in the evolution of firms.

3.2.4 Coevolutionary dynamics of the firm

The dynamics of firms have seen seven major transformations (Christopher, 2005). These changes are in the context of the market's movement from supplier-driven mass production to market-driven mass customization. The transformations are summarised in Table 3-1. First we have the critical transformation from supplier-centric to customer-centric by a re-focusing from cost minimization to creating customer value by increased agility responding to customer requirements. Second there is move away from production-pull to demand-pull refocusing from production optimization to make on demand. Third, is a change from forecasting and the building of inventory to the use of information to acquire inventory based on customer demand. Fourth, there is the transformation to long-term relationships and the retention of customers, moving away from one-off transactions.

Transformation	Re-focusing	Outcome
From supplier-centric to customer-centric	Change in emphasis **from cost minimization** by batch-oriented production process and efficient distribution **to agility** by customer responsiveness in a highly competitive market-place	Value not Cost; Customer insight; emphasises uniqueness and regular refreshing of Supply Chain Network offering
From push to pull	Similar to above, moving **from production push** which optimizes operations **to demand pull** in which items are made on demand, similar to Japanese Kanban	Production on demand; management of complexity.
From inventory to information	From **forecast-driven, demand prediction** and inventory build to **demand-driven** inventory acquisition in a more unpredictable volatile market by better visibility of real demand and shared information upstream	Inventory acquisition on demand by use of information systems and underlying ICT
From transactions to relationships	From **transactional accounts** to long-term **customer retention oriented relationships**	Customer retention by long term supply chain partnerships; market segmentation
From 'truck and sheds' to end-to-end pipeline management	From **transportation and warehousing** efficiencies (distribution management) to logistics / SCM and end-to-end coordination of the pipeline	Time compression of entire pipeline and 'cost-to-serve' understanding
From functions to processes	From **traditional functional** organizations (convenient for resource allocation and personnel development) to **cross-functional** (team-based centres of excellence) and market-facing business processes.	Value creation; cross-functional understanding
From standalone competition to network rivalry	From conventional business model of company competition using **own resources** and competencies to an extended enterprise competition drawing on a complex network of **specialist providers of resources** and competencies.	Collaborative working with supply chain partners. Relationship Management

Table 3-1 Business Transformations (Christopher, 2005)

with customers. Fifth we have the transformation from a firm-focused distribution and logistics mindset to a supply chain/end-to-end pipeline culture. Sixth there is the move away from a functional/silo structure to a cross-functional business process oriented organization. Last is the transformation away from the creation of in-house resources and competencies to the use of a wider network of specialist providers.

These major changes are evident in much of the organizational transformation literature. It is not surprising that power has shifted down-stream and so closer to the end customer, moving the power from manufacturers to retailers (Bowersox, 1996). This shift in market dynamics, fuelled by business process reengineering, forces suppliers and manufacturers to offer a greater variety of products tailored to customer needs causing an increase in the quantity of item level information (Bowersox et al., 2000). The rise of the information age and greatly reduced information communication costs is changing coordination mechanisms among partners in the supply network (Coase, 1998), increasing collaborative work within teams on high capacity networks (Tapscott, 1996) enabling continuous information flow in an integrated supply network (Lambert and Cooper, 2000) and providing new opportunities for customers to connect to supplier and to reduce transaction costs and risks (Lewis and Talalayevsky, 2004).

Organizational cultures and structures influence performance, for example, Japanese firms which stressed competitiveness (markets) and entrepreneurship (adhocracies), outperformed companies dominated by internal cohesiveness (clans) and by rules (hierarchies) (Deshpandé et al., 1993). Feedback operates and can be amplified (Arthur, 1994) or act to self-regulate (Capra, 1996). The transformation of the firm is thus an emergent process, accessed and influenced through disequilibrium, positive feedback and also order-generating rules (more on this in chapter 4) (MacIntosh and Maclean, 2001).

However, a firm does not always realize a direct and linear benefit from belonging to one or more supply networks. For example, in a study of dyadic relationships, it was found that performance is not symmetrical upon the partners and can be opposite, e.g. one realising its objectives and the other not (Gulati, 1998; Gulati and Gargiulo, 1999). It can also arise, that a partner in a network benefits from information contained within the network, creating learning races (Gulati et al., 2000). In another study of first tier suppliers to the automotive industry, customer service was found to mediate the relationship between firm performance and an integrated supply chain strategy (Vickery et al., 2003) supporting the need for a customer-focused supply chain philosophy. Increased competitive advantage can also rise from supply networks in which firms are legally and spatially separated (Yusuf et al., 2004).

Porter (1990) takes a firm-centric perspective, recommending that alliances are used only selectively; firms make profits or go bankrupt, not alliances or networks, because firms are replaceable, particularly in a global context. Thus there is a risk not only of poor performance, but also of survival by belonging to supply networks. On the other hand, successful membership of supply networks can influence both performance and longevity. Thus supply networks confer constraints and benefits (Gulati et al., 2000): constraints can be disadvantageous such as lock-out of profits or lock-in to a failing network; conversely, benefits may accrue due to lock-in to a profitable network or lock-out of a failing network.

This sub-section considered the coevolutionary dynamics of the firm and the transformations that firms are undergoing in order to increase performance.

3.2.5 Summary

This section has taken a firm perspective to evolution. It has described ways of classifying and describing similar firms. The coevolutionary dynamics of firms have been examined using mainstream literature.

Taking the firm as the unit of analysis in the context of a supply network creates two limiting factors: first, the boundary to evolution is limited to the firm, which has to demonstrate qualitative change for it to have evolved; and the methods for evolution are inwardly focused, denying the ecology in which the firm persists by treating it exogenously. These limiting factors create paucity in our understanding of complex economic systems in all but a handful of relatively isolated, static firms.

Firms exist within a wider ecology encompassing other firms, professional institutions, land and air space, infrastructure (physical and informational), assets (physical, human and knowledge) and so on. Connections between firms which exist at multiple, cross-cutting layers and join together such various components within and across the ecology in the creation of supply networks provides the appropriate unit of analysis.

The next section looks at the evolution of the supply network.

3.3 The Evolution of the Supply Network

The subject of this section is the inter-firm connections that construct a collective entity which as a system create, manufacture and deliver products and services to customers. Sub-sections look at four topics. First is the history of supply network perspectives and their positioning in different environmental paradigms. Second is the nature of inter-firm relationships and networks. Third is a review of supply network archetypes. Fourth is the nature of coevolutionary dynamics of the supply network.

3.3.1 A history of supply network perspectives

The concept of the supply network has developed through a number of observable stages: from connecting intra-firm components of inbound materials and outbound products; to dyadic (two-sided) supplier relationships in which each firm attempts to manage immediate suppliers; to dyadic chains which extend the relationships of the firm to both to customers' customers and suppliers' suppliers; to supply chain management in which all organizational supply chains are managed holistically; to integrated business networks which manage multiple businesses that create products and service packages; to demand chain communities, which manage multiple enterprises practicing agility to customer demand. These are shown in Table 3-2.

The growth of the supply chain discipline has however been fragmented (see Harland (1996) for a review), with differing and even disparate themes emerging in the field, crossing many traditional research boundaries, such as Operations Methods, Logistics and Strategic Management. Multiple definitions of the Supply Chain and Supply Chain Management are to be found in the literature. Mentzer et al (2001) provide a helpful classification of the literature into three categories: 1) a management philosophy, 2) the implementation of a management philosophy and 3) a set of management processes. The most advanced management philosophy is that of the supply chain as a system or single entity, optimizing the entire chain (1997) and managing the flow of a distribution channel through multi-firm effort, from the supplier to the end user (Ellram and Cooper, 1990). This philosophy is consistent with Harland's (1996) network, the most mature form of supply chain conceptualisation. Supply network visualizations are shown in Figure 3-3.

Stage of development	**Type of trading relationship**	**References**
Intra-business chain	Internal supply chain integrates business functions involved in the flow of materials and information from inbound to outbound ends of the business	Harland (1996)
Dyadic relationship	The management of dyadic or two party relationships with immediate suppliers; Extended to downstream distribution channels and upstream production chains; Structure and scope of supply chain consists of material and information processing units: demand, value-adding transformation and supply	Harland (1996) Womack & Jones (1990); Davis (1993) Womack (2002)
Dyadic chain	The management of a chain of businesses including a supplier, a supplier's suppliers, a customer and a customer's customer, and so on	Harland (1996)
Supply chain	Management of multiple company relationships (SCM); Managing and coordinating multiple business activities across functions and firms, and viewing the supply chain as a single entity, rather than as a set of separate functions.	Lambert, Cooper and Pagh (1998); Mentzer et al (2001); Larson & Rogers (1998); Christopher (2005; 1992)
Integrated business network	The management of a network of inter-connected businesses involved in the ultimate provision of product and service packages required by end customers	Harland (1996)
Demand chain communities	Demand driven, agile, multi-enterprise organizations, increasingly complex with various inter-relationships between companies, growing number of participants which does not remain constant throughout product life cycles; unlike old models where customer orders were delivered from on-hand inventories.	Hewitt (2000); Lummus & Vokurka (1999); Bowersox et al (2000)

Table 3-2 The Development of Supply Network Perspectives

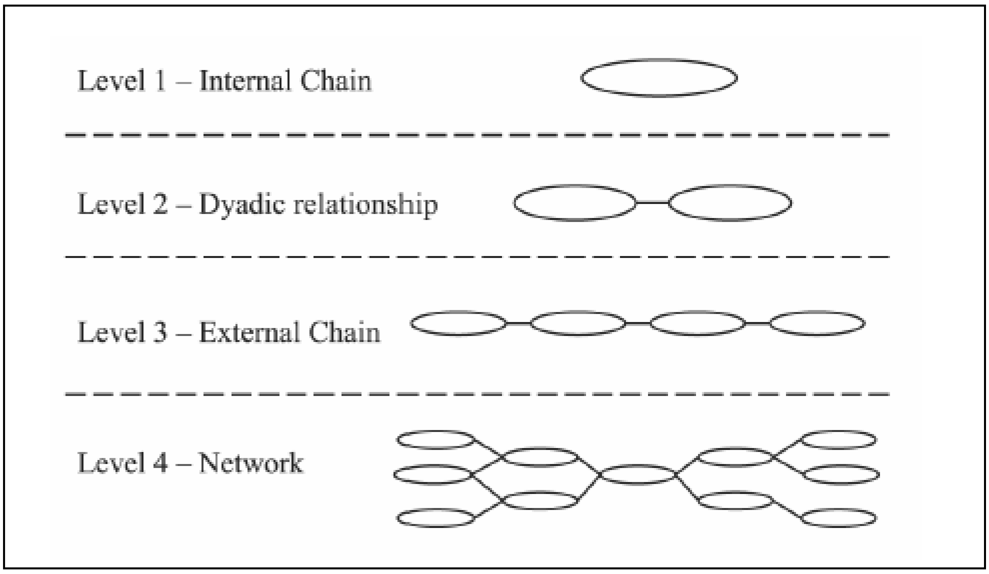


Figure 3-3 Supply Network Visualizations (Harland, 1996)

Traditionally, the focus of supply chain management has been on inputs and outputs to the firm. This is because the method of internal management is known to impact local firm performance (Mintzberg, 1979). Indeed the importance of supply chain management is its inter-firm focus. *"The leading-edge companies … seek to make the supply chain as a whole more competitive through the value it adds and the costs it reduces overall. They have realized that the real competition is not company against company but rather supply chain against supply chain"* (Christopher, 1992: 14). This definition raises the importance of the systemic, strategic orientation to the whole chain which is necessarily required of every partner in the supply chain. These organizational relationships tie firms to each other and to the success of the entire supply chain, which may then function as a firm in its own right with its own identity (Cooper et al., 1997).

This systems perspective requires the analysis and management of the entire network in order to achieve the best outcome for the whole system (Cooper and Ellram, 1993). The philosophy is also consistent with the logistics paradigm that integrated performance produces superior results to that of loosely managed functions (Bowersox, 1996). Thus each firm in the supply network directly and indirectly affects the performance of all other supply network members as well as ultimate supply chain performance (Cooper et al., 1997).

Facilitating the exchange, be it of goods or information, between firms in a supply network becomes critical to the smooth operation of the supply network. The role of the logistics firm in facilitating the exchange is to synchronize activities among the partners in the supply network with the aim of gaining and integrating knowledge. Applications of new technologies, particularly Information, Communication Technologies (ICTs) must be synchronised across the network to streamline management processes and provide efficiency and productivity improvements across the length of the supply chain (Chapman et al., 2002). Since the inception of inter-firm organization, there has been an increasing focus on the use of ICT. Giannakis et al (2004) mapped the theoretical developments that influenced supply chain management and identified four eras: the post-war, computerization, globalization and the current internet era. These resemble the environmental paradigms described in Chapter 2 and a cross-reference is included in Table 3-3.

Giannakis et al (2004) chart the political, economic and technological developments and so contextualise the evolution of supply chain theories. The major institutions which contributed to the development of supply chain theory are also introduced, including the International Motor Vehicle Programme (IMVP) which spawned key contributions on lean supply chains, such as The Machine that Changed the World (Womack and Jones, 1990) and Value Streams (Hines et al., 2000). Each era appears to span 15-20 years and so we may be on the threshold of a new era. Ma (2006) mapped supply chain activities over the decades from the 1950s, demonstrating the increasing integration of firms and logistics capabilities as shown in Table 3-3. Since the late 1990s, the evolution of supply chain management has shifted to IT (Ho et al., 2003), management (Chapman et al., 2002), and lean, JIT and agile (Womack, 2002; Gunasekaran, 1998).

The next section discusses supply network relationships and their related behaviour, which are embedded with the governance arrangements of the supply network structure.

Date	Key activities (Ma, 2006)	Era (Giannakis et al, 2004)	Globalization Paradigm (see Table 2-2)	
1950s and early 1960s	Separate activities in SC; No real liaison between distribution related functions	Post-war	Schumpeter IV	End of 1st Globalization
1960s and early 1970s	Fragmentation of distribution; Inter-related activities could be linked together and managed more effectively; Relationships between functions recognised, enabled a systems approach and total cost perspective	Computerization	Schumpeter V	
1970s	Centralisation of logistics; Change in structure and control of distribution chain; Total cost management			Age of ICT, 2nd Globalization
1980s	Clear definition of true costs contributed to professionalism within distribution; Longer term planning, including centralized distribution , severe reductions in stock-holding, use of computers for information and control; Growth of third party distribution services	Globalization		
1980s early 1990	IT and emphasis on information aspects; Integration of Logistics and cost control			
1990s	Process integration beyond firm boundaries – SCM; Partnerships and alliances, plus intermediaries; Gulf War gave rise to aspects of modern logistics channeling	Internet		3rd Globalization
2000 onwards	Fierce competition, redefinition of business goals and re-engineering of entire systems; Business importance and added value of logistics recognised			

Table 3-3 Supply Chain Evolution

3.3.2 Supply network relationships

Levels of analysis of inter-firm relationships have included the dyad, the chain and the network. Croom et al (2000) show how each level of analysis requires a different focus dependent on the element being exchanged which may be: assets, information, knowledge or relationships.

3.3.2.1 Supply chain conceptualizations

The dyadic and supply chain conceptualizations simplify the nature of the supply network in three major respects. First, firms are treated as having static relationships but in practice individuals within each firm have relationships with individuals in other firms, dispersed across the firm and working at different points in the product life cycle, e.g. at design, manufacture, operation, etc. This dispersion of roles occurs because of the functional specialisms of staff. As a consequence there is a probability of loss of information, which also occurs due to the turnover of staff. Each person also has a potentially unique perspective, or a 'virtual' view of the supply chain (Mouritsen et al., 2003) so even if information if fully and accurately shared, it may be interpreted differently. Each person's interpretation is the consequence of their previous experiences and beliefs, so is based in personal histories and is thus path-dependent. And these beliefs are refined as individuals learn through the process of interaction with other systems. So each firm's networks are idiosyncratic and have followed a path dependent process (Gulati and Gargiulo, 1999) conferring competitive advantage as they are not easily imitated or substituted. Furthermore, we can say that each person's view is partial, with no one person having a complete and full view of the supply network. The supply network can therefore be viewed as an evolving system of multiple, heterogeneous, dynamic, path-dependent actors in purposeful relationships.

Second, the individuals in a firm are likely to operate in multiple supply chains concurrently, some of which may be in a state of development or demise. In a simple case, where a firm produces only one product, it is likely to require multiple suppliers for the different components such as electrical parts, mechanical parts, raw materials, etc. The firm that produces many similar products may be able to source common parts from a single supplier but this may cause prioritization conflicts for the firm at times of short supply. The firm that produces many different products will need to operate concurrent relationships with many sets of suppliers. This process of supply chain management, i.e. the management of a variety of supply chains *within one* firm, creates opportunities for and constraints upon firm performance. Each supply chain may have requirements placed upon them that contradict the requirements of another. The firm's competitive success will depend on its ability to participate in different supply chains, which itself affects the competitiveness of the other supply chains (Sinha et al., 2004).

Third, a firm may have many customers. Some of these customers will be transactional, whilst others will be strategic and reflect investment in long-term and significant relationships. In a simple scenario, the firm has one customer. However, this customer may require multiple products with different delivery times and priorities. In the 21st century, mass customization is a focus requiring significant variety in terms of product look and feel exacerbated by a host of tricky operational problems, such as delivery to various locations, fluctuating demand over time and so on.

Thus there are three types of potential firm arrangement:

- simple – 1 supplier to 1 customer
- one-sided – n suppliers to 1 customer; 1 supplier to n customers
- many-to-many – n suppliers to m customers

Regardless of the number and type of supply chains in operation, a firm's infrastructure services, such as Human Resources Management, ICT services, facilities management, commercial services, strategic marketing and procurement, etc are finite resources, providing services to staff engaged in multiple supply chains. The effect on the firm is that concurrent supply chains vie for the firm's infrastructure resources. And these resources may be different in each firm within the supply network. Ultimately, the network structures and behaviours needed to effect inter-firm cooperation and coordination are paramount to achieving successful performance. The balance of cooperation (and permitted emergence through positive feedback) and coordination (control managed by negative feedback) is a strategic issue for the design and operational performance of the supply network (Choi et al., 2001).

3.3.2.2 Strategies for compatibility

It is not surprising that inter-firm relationships have been the subject of significant research. Relationships have often been studied as dyads of different types of agents. Perhaps the most well known is that of the iterated prisoner's dilemma in which fundamentally selfish agents will spontaneously cooperate (Axelrod and Hamilton, 1981; Axelrod and Hamilton, 1984). Various long-term strategies were devised with contributions from the academic community and the success of each was evaluated, showing that a Tit-for Tat strategy was the most successful.

In their typology of inter-organizational relationships Astley and Fombrum (1983) describe two forms of interdependence: commensalistic, in which firms belong to the same specie; and symbiotic, in which firms are from different but complementary species. They show how the forms of control and the structures of coordination differ depending on the form of interdependence.

In coevolution terms, three types of relationship are identified: predator-prey, symbiotic and parasitic (NECSI, 2007). The prey is part of the predator's environment, each evolves characteristics (speed, stealth, camouflage etc) in order to avoid or consume the other respectively. Organisms in a symbiotic relationship evolve together; each is part of the other's environment, adapting to their environment and benefiting from each other. In a parasitic relationship the parasite lives off the host, harming it and possibly causing its death, although, short-term, this is not in the interests of the parasite. There is close proximity between host and parasite. Other symbiotic relationships can help remove parasites.

In a supply network there are many dyadic relationships, some of which are commensalistic and others symbiotic. This is one of the complicating factors of supply networks which lead to complex governance and structural forms. The appropriate mix of types of firms and types of relationship, have been evaluated at the system or network level. Analyses of the most effective strategic alliances (or long term inter-firm relationships) indicate that there needs to be some level of similarity but also some level of difference (Parkhe, 1991). Bucklin and Sengupta (1993) define organizational compatibility as having complementary goals and objectives in addition to similarity in operating philosophies and corporate cultures. Strategic alliances (Gulati, 1998) can be established anywhere along a continuum of governance structures, with joint ventures at one end, closely replicating the hierarchical controls of firms, and networks at the other end with no hierarchical controls. The treatment of alliances as independent, ahistorical events is identified as a shortfall in recognizing the embeddedness of relationships created by social ties and therefore a different requirement for governance. Alliances are also concerned with process because exchanges are not single, but multiple over time and with value maximization, not only cost minimization (Gulati, 1998).

3.3.2.3 Types of relationship

Strategic alliances are nevertheless focused at dyads of firms where the supply network often incorporates many numbers of dyadic relationships, each of which can be very different. The use of linear constructs in the notion of supply chain depicts a simple topology of aligned goals, when the arrangement is more similar to a supply web; predators and prey are related in various ways within a complex non-linear structure (Brown et al., 2005). According to Webster Jr (1988) these networks are the complex, multifaceted organizational structures that result from multiple strategic alliances.

A richer description of the nature of supply networks is provided by inter-organizational networks (IONs). Nassimbeni (2004: 46) defines the inter-firm network as one in which: "*two or more agents, at least in part autonomous, which gives rise to an exchange relationship, according to certain modalities and forms*". The structure of the ION depends on the individuals engaged in the relationship and the overall architecture of these systemic relationships. The content describes what is exchanged and the modalities and forms define the governance of the relationship and how it may adapt, coordinate and safeguard exchanges. The number of members is relevant as successful supply chain cooperation is possible with fewer partners (Lambert et al., 1998; Spekman et al., 1998; Goffin and New, 1997). Webster Jr (1992: 9) suggests that the basic characteristic of a network organization is a confederation, defined as *"a loose and flexible coalition guided from a hub where the key functions include development and management of alliances themselves, coordination of financial resources and technology, definition and management of core competencies and strategies, development of relationships with customers and management of information resources that bind the network".*

The description of a supply network as a confederation helps to highlight the problem of many autonomous firms with the dual interests of their own success and network success. The uniformity of the firms in the supply network with respect to supply network goals or customer orientation has been used to bind the firms. Methods such as ECR (Efficient Consumer Response, for example (Lee and Whang, 2000)) which create homogenous perspectives towards customers demonstrate how synchronised perspectives deliver goal alignment and consistent messages, leading to improved supply chain performance. We can therefore say that the extent to which individual perspectives within a particular supply chain are homogeneous is an indicator of supply chain performance. Christopher (1985) surmises that the key to success within this new competitive framework is the way in which the network of alliances and suppliers is 'welded together' to achieve mutually beneficial goals.

Supply networks are idiosyncratic, having followed a path-dependent process (Gulati and Gargiulo, 1999) to reach their current evolutionary state. The supply networks to which a firm belongs provide competitive advantage as they are not easily imitated or substituted. Christopher (2005) argues that we are now entering an era of network competition. Individual businesses no longer compete; it is supply networks that compete, and economic exchange is embedded in the particular network structure (Powell, 1990).

Supply networks, as the combination of firms which can better structure, co-ordinate and manage the relationships with other firms in the network will be the most successful at delivering superior value to the market place. The problem of coordination strategies which lead to adaptive, flexible and collective behaviour in the supply network is one of the major challenges in supply chain management (Surana et al., 2005).

A network structure has implications for the traditionally hierarchical 'pyramid' structures of firms. The network acts as a virtual organization or confederation in which specialist skills and capabilities are provided by the network members. This is particularly relevant where the use of novel construction materials plus automated manufacturing processes lead to sophisticated airframe configurations requiring scarce specialist and agile resources, for example the joint venture HYTRI (Assembly Automation, 2005).

3.3.3 Supply network archetypes

Christopher (2005) surmises that the key to success within this new competitive framework is the way in which the network of alliances and suppliers is 'welded together' to achieve mutually beneficial goals. This sub-section exposes supply network archetypes and identifies the variables which enable supply networks to be differentiated.

3.3.3.1 Supply network orchestration

The rationale for managing, co-ordinating and focusing the value creation network (Supply Chain Orchestration) is that there needs to be a "*common agreed agenda driving the achievement of the supply chain goals and a supply chain strategy that is subscribed to by the entities in the chain*" (Christopher, 2005: 292). Usually the Orchestrator is the most powerful member of the network however the logistics firm has a key role in synchronizing partner activity throughout the supply chain, such as the use of information technologies (Chapman et al., 2002). Orchestration is usually driven by the prime (Chapman et al., 2002) who carries out the management and coordination of multiple business activities across functions and firms (Lambert et al., 1998; Mentzer et al., 2001) guided from a hub where key functions are managed (Webster (Jr), 1992).

In the case where suppliers are wholly owned, vertically integrated or where the organization owns a significant part of the supplier, governance is achieved via a hierarchy of controls. Hierarchical control indicates the ability of the firm to control and mandate the action of each member to benefit of the entire supply network. Hierarchical controls often assume a transaction cost perspective, for example see Carroll and Teece (1999).

The use of hierarchical structures attempts to improve coordination and reduce costs by minimising relationships between the parts of the substructure. The consequence of creating a hierarchy means a reduction of information accuracy and timeliness because of the need to pass on information. A hierarchy also creates issues of resilience as the parts become minimally connected (Lewis and Talalayevsky, 2004) and the strength of the supply chain depends on the integrity of the links (Davis, 1993).

Whilst vertical integration was a fashion of the 1980s, much of it ‘unwound’ in the 1990s when there was a general change in the desire of firms to integrate vertically towards one of cooperation rather than maintaining skills and resources within the firm (Bales et al., 2004). We see this on a global scale, for example, where restrictions on foreign direct investment in local aerospace firms is being lifted (Komarov, 2006).

3.3.3.2 Collaboration and coordination

Bales uses empirical evidence to show that an increase in partnering, information exchange and evolving supply network structures, the relationship with other firms has moved from adversarial towards one of an integrated network. The supply network of the 2000s is more akin to a heterarchy or to give its ancient Greek meaning “*under the governance of an alien*” (von Goldammer et al., 2007: 1). Contemporary thinking believes that in an heterarchical environment, relationships are key to influencing decision-making. Where relationships exist between firms, that is, where an individual or group in one firm can influence the decision making of an individual or group in another firm to some extent, the supply chain acts as a supply network. The reduction in vertical integration has pushed information sharing down the supply network, resulting in a loss of direct visibility to OEMs (original equipment manufacturers) and a loss of some of their power (Bales et al., 2004).

The issue of influencing independently owned firms within a heterarchy requires coordination mechanisms. A supply network can be defined as a group of semi-independent fims which collaborate in “ever-changing constellations” in order to achieve some business goal related to the collaboration (Tapscott, 1996; Akkermans, 2001).

Mulford and Rogers (1982) define coordination as the establishment of decision rules between two or more firms to deal collectively with the shared tasks in their environment, whereas cooperation is focused on the joint achievement of firm goals.

The need to coordinate assumes that cooperation is needed between firms. Soft or intangible capabilities are particularly important competences for strategic operations (Lewis, 2003). Cooperation heightens the need for communication, and for information technologies and associated software to support that communication (Castells, 1996). The need to cooperate and leverage complementary competencies within the network becomes essential (Yusuf et al., 2004). Collaboration happens globally; Boeing collaborates with European aerospace firms to jointly design airframe components. But these endeavours are huge, expensive undertakings beyond the means of one firm alone. So the efficiencies of collaboration are significant enough to overcome the "*logistical hassles, security issues and general mistrust that tend to isolate U.S. companies*" (Pastore, 2004: 1).

Coordination becomes a formalised way of cooperating (Beerkens, 2004) where cooperation is defined as a voluntary cooperative agreement. Beerkens suggests that the ultimate step of cooperation is amalgamation and where amalgamation becomes merger or acquisition, a hierarchy comes into being together with a loss of autonomy. It follows that formal cooperation potentially leads to ownership.

3.3.3.3 Supply network relationships

Information technology is driving more tightly coupled relationships than those usually found in supply chains, as it enables closer coordination and reduces costs without the need for ownership or control (Lewis and Talalayevsky, 2004). Conversely, established business processes for the purposes of purchasing and supply are inclined to block or corrupt potential inter-organizational capabilities (Lamming et al., 2001).

Inter-firm network relationships although often established by firms as formal contractual relationships with bureaucratic structures, will develop on a dynamic, organic basis of continuity, reciprocity, cooperation, informality and social embeddedness (Sydow and Windeler, 1998). As the inter-firm relationship develops, a structure is exposed but governance of the structure becomes more problematic to implement as the structure is 'owned' by multiple firms with only partial control.

Compared with organizational hierarchical relations, the network is more loosely coupled, relies more on self-organizing processes and has greater competitive pressures (Ring and Van de Ven, 1994). But, strong ties may improve the probability of oligopolistic coordination more than weak ties (Galaskiewicz and Zaheer, 1999). This emphasis on longer term relationships reduces market focus which would otherwise exist in a supply networks (Cohen and Agrawal, 1999) but this is mitigated somewhat by unequal distribution of costs and benefits between the supply network partners making inter-company cooperation difficult (Kärkkäinen et al., 2003).

Management and coordination of inter-firm activity within a supply network should be open to the movement of functional activity to its optimal location which may improve the viability of various supply network structures (Mentzer et al., 2001). These movements must be cognisant of third party providers and how the relationships between firms are managed. Such functional movements are almost impossible in a market as a firm is selected for the function it provides; within a keiretsu (owned supply chain) these movements should be easiest. Governance prevents finding an optimal supply chain structure.

3.3.3.4 Supply network structure

We have thus identified three dimensions of supply network structure. First is ownership: the hierarchy which is fully integrated and the heterarchy with no shared ownership of supply network members acting like a market. Second is control: leveraged by coordination or cooperation. Third is relationship: short-term, market focused or long-term, supply network focused.

This sub-section opened with the notion of the supply network Orchestrator, often being the most powerful member of the network. The role of the Orchestrator is found evident in two alternative ways to organize a supply network: the 4PL and the Keiretsu.

The introduction of the 4PL™ (fourth-party logistics service provider) business model to manage the modern supply network was originally copyrighted by Accenture. The

4PL, or sometimes referred to as the *lead logistics provider*, provides systems architecture and integration skills, houses a control room for decision-makers, acts as supply chain infomediary using its own information systems and manages access to the best of breed asset providers. The 4PL is thus a hybrid firm typically formed from parts of other firms as a joint venture or long-term contract. The Orchestrator essentially passes control to the 4PL who then exerts control over the supply chain. International joint ventures can take some time to deliver cost, delivery, quality and innovation expectations (Lihong and Goffin, 2001).

Keiretsu, originally from Japan, is a form of network governance implemented in a vertical or horizontal form. The vertical keiretsu is a hierarchy, however, the horizontal keiretsu operates with a main bank and cross shareholdings. A distribution Keiretsu is also possible (Miyashita and Russell, 1995). Partner firms belong to only one Keiretsu and in that way control is maintained over member firms. Ellram and Cooper (1993) identify similarities and differences between the Keiretsu and the Supply Chain Management approach, reproduced in Figures 3-4 and 3-5.

Similarities between Keiretsu and traditional supply chain management include a long-term time horizon, joint planning, information sharing, and the sharing of risks and rewards, and compatible corporate philosophies. Differences are that the Keiretsu exerts more control, requires participation by the nature of the shared ownership has high strategic coordination and is more secretive, being more akin to traditional business relationships. Strategic networks are an example of strategic coordination, see Jarillo (1993) for example.

The legacy of western management attitudes and anti-trust laws, which give primacy competition and independence, have prevented the implementation of close relationships unlike the Keiretsu approach (Ellram and Cooper, 1993) which has created some very competitive channels.

Similarities Between Keiretsu and Supply Chain Management

Element	Perspective
Time Horizon	Long-term
Information Sharing and Monitoring	Critical to support long-term perspective
Coordination of Multiple Levels in the Channel	Critical to achieve benefits such as inventory reduction, other synergies
Joint Planning	Required to support long-term coordination
Compatible Corporate Philosophies	Important for long-term coordination
Reduced Supplier Base	Required for coordination, management and economies
Channel Leadership	Required to coordinate efforts, provide direction
Sharing of Risks and Rewards	Helps strengthen relationship, builds trust and commitment
Speed of Operations, Information and Inventory flows	Major goals of the system

Figure 3-4 Similarities between Keiretsu and Supply Chain Management (Ellram and Cooper, 1993)

Differences Between Supply Chain Management and Keiretsu

Element	Supply Chain	Keiretsu
Cultural roots	Counter to traditional western competition, driven by economic necessity	Congruent with traditional business relationships
Control	Less	More
Participation	Voluntary	Ownership interest is common
Dependence	Less Commitment	More dependent
Strategic coordination	Relatively low	High
Security of strategic information	More difficult to keep secret, control	More secretive, controlled

Figure 3-5 Differences between Keiretsu and Supply Chain Management (Ellram and Cooper, 1993)

3.3.3.5 Summary

This sub-section has identified structural and behavioural features of different types of supply network: the hierarchy (vertically integrated network); the market (no ex-ante relationship); the 4PL (or joint venture); the Keiretsu; the heterarchy (some ex-ante relationship). The next sub-section analyses the effect upon each type of supply network for each type of construct that a firm might adopt. We thus find a way of differentiating between supply networks.

3.3.4 Analysis of archetypes

Five distinct archetypes from literature describe the variety of supply networks in the population of manufacturing firms. These archetypes are the hierarchy/owned supply chain; the Keiretsu; the joint venture or 4PL; the heterarchy or network; and the market. Some have argued that the hierarchy and the market are not types of supply network: A supply network can be implemented in several forms, but the network structure fits neither "market" nor "hierarchy" categories (Powell, 1990). There are however similarities between markets and networks, and hierarchies and networks. Where no relationships exist ex-ante, the new supply network acts more as a market in which prices determine the selection of the supplier, otherwise it acts more as a hierarchy, with the adoption of existing control mechanisms. Markets and networks are similar in that they have unconnected ownership structures but, for networks, governance is implemented with informal coordination methods in which relationship continuity incentivizes collaboration (Nassimbeni, 2004).

The firm’s constructs described in this chapter are used as a method to differentiate between supply network archetypes (see Table 3-4). The rationale for adopting a construct within the firm but relating to the supply network may be for a variety of performance outcomes, such as cost or innovation. However, the adoption of particular constructs may contribute negatively or positively to particular network(s), depending on their archetype.

Firm constructs	Owned supply chain	Keiretsu	Joint Venture or 4PL	Heterarchy or Network	Market	How does it favour the firm?
Accelerate outsourcing trends	Reduce size of owned supply chain; favours markets or networks	Increase in partners or use of partners in Keiretsu	Increase in partners or use of market	Increase in network or use of networked member	Increase in suppliers or use of existing market supplier	Cost; Process Innovation; Reduces control of SN
Focusing more on core competencies	Reduce size of owned supply chain; favours markets or networks	May take work from other members	Mergers with other specialist firms, more work for firms doing non-core work	Mergers with other specialist firms, more work for firms doing non-core work	Takeovers of specialist firms, more work for firms doing non-core work	Specialist and finding niche
Increasing industry-wide collaboration	Risk of losing specialist knowledge	Only if collaborator s join Keiretsu	Some risk of losing specialist knowledge	Improve network performance	No change	Standardisatio n and ability to integrate; Reduces competitive-ness
Embracing more "best value" providers from outside the industry	Increase owned chain and/or shake out poor performers	Increase members and/or shake out poor performers	Increase partners and/or shake out poor performers	Increase partners and/or shake out poor performers	Positive	Innovation; Use of low cost economies for cost reduction
Adoption of industry trends; Replication of formula	Cost may exceed benefit	Improves operational perform-ance especially if all members change	Improves operational performanc e especially if all members change	Improves ability to integrate	Improves ability to share information	Standardisa-tion
From supplier-centric to customer-centric	Increase in agility required	Increase in agility required	Increase in agility required	May already be adequately agile	Adequately agile	Reduce risk of unsold products Get closer to customer
From push to pull	Forces increased perform-ance in owned SC	Forces increased perform-ance in Keiretsu	Requires flexibility depending on demand	Increase probability of use of network or market	Increase probability of use of market	Reduce inventory; Increase risk of production slowdown
From inventory to information	Improved decision making/ intervention	Improved decision making/ intervene-tion	Negligible	Improve network performance to the detriment of some firms	Favour firms with capabilities to supply information	Reduce waste and loss; Increase cost of information management

Firm constructs	Owned supply chain	Keiretsu	Joint Venture or 4PL	Heterarchy or Network	Market	How does it favour the firm?
From transactions to relationships	Negligible	Negligible	Negligible	Positive	Small positive	Increase cost to manage relationships; positive in time of increased or changed requirements
From 'truck and sheds' to end-to-end pipeline management	Redistribute resources to optimum location in supply chain	Redistribute resources to optimum location in supply chain	Negligible if established at outset; difficult to change	Difficult	Possible	Increase control over supply chain
From functions to processes	Improves integrated behaviour	Improves integrated behaviour	Negligible if established at outset; difficult to change	Difficult without integrated behaviour in all parties	Difficult without integrated behaviour in all parties	Intra organizational synergy
From standalone competition to network rivalry	Exclude others and risk lock-in	Exclude others and risk lock-in	Exclude others and risk lock-in	Positive reinforcement of network partners	Positive reinforcement of valued market members	Can mean collapse of firm if it is not a strong cog in the network

Table 3-4 Firm constructs affecting the supply network

Table 3-4 is mapped quantitatively using a scale -2 to +2. A very low score indicates a damaging effect of the action of the firm upon the supply network structure. A very high score indicates a highly constructive effect. Whilst the assignment of simple scores is subjective, the intention is to draw overall comparisons between the types of supply network. The list of firm constructs may be incomplete. A check was completed to ensure that no collinearity was present.

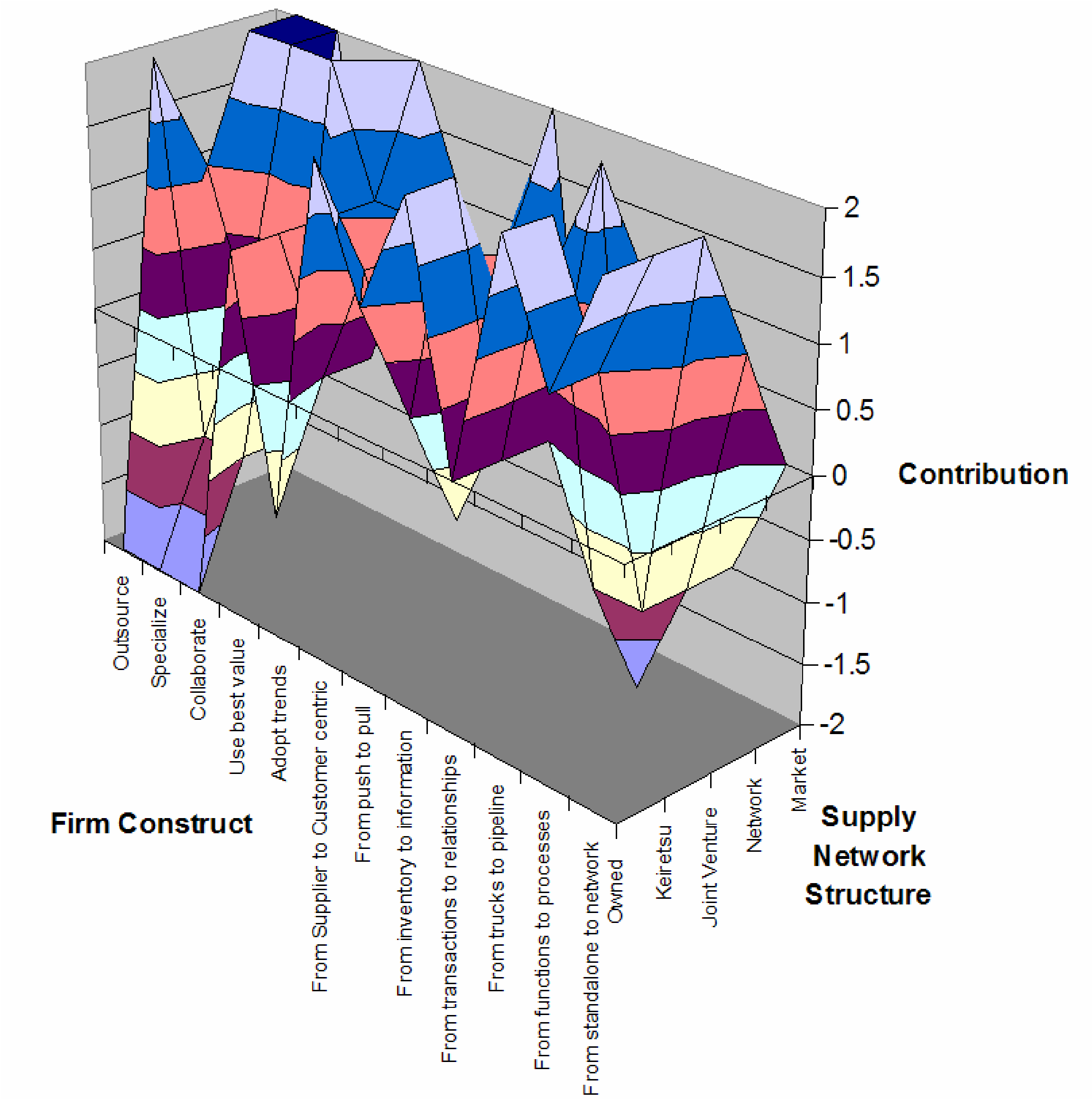


Figure 3-6 Firm constructs showing effects on supply network structure

Figure 3-6 shows the positive or negative effect of each firm construct upon the various types of network archetype. Mostly, the constructs confer positive contributions to supply networks (above 0), but note how outsourcing and focusing on core competencies is detrimental to an owned supply chain.

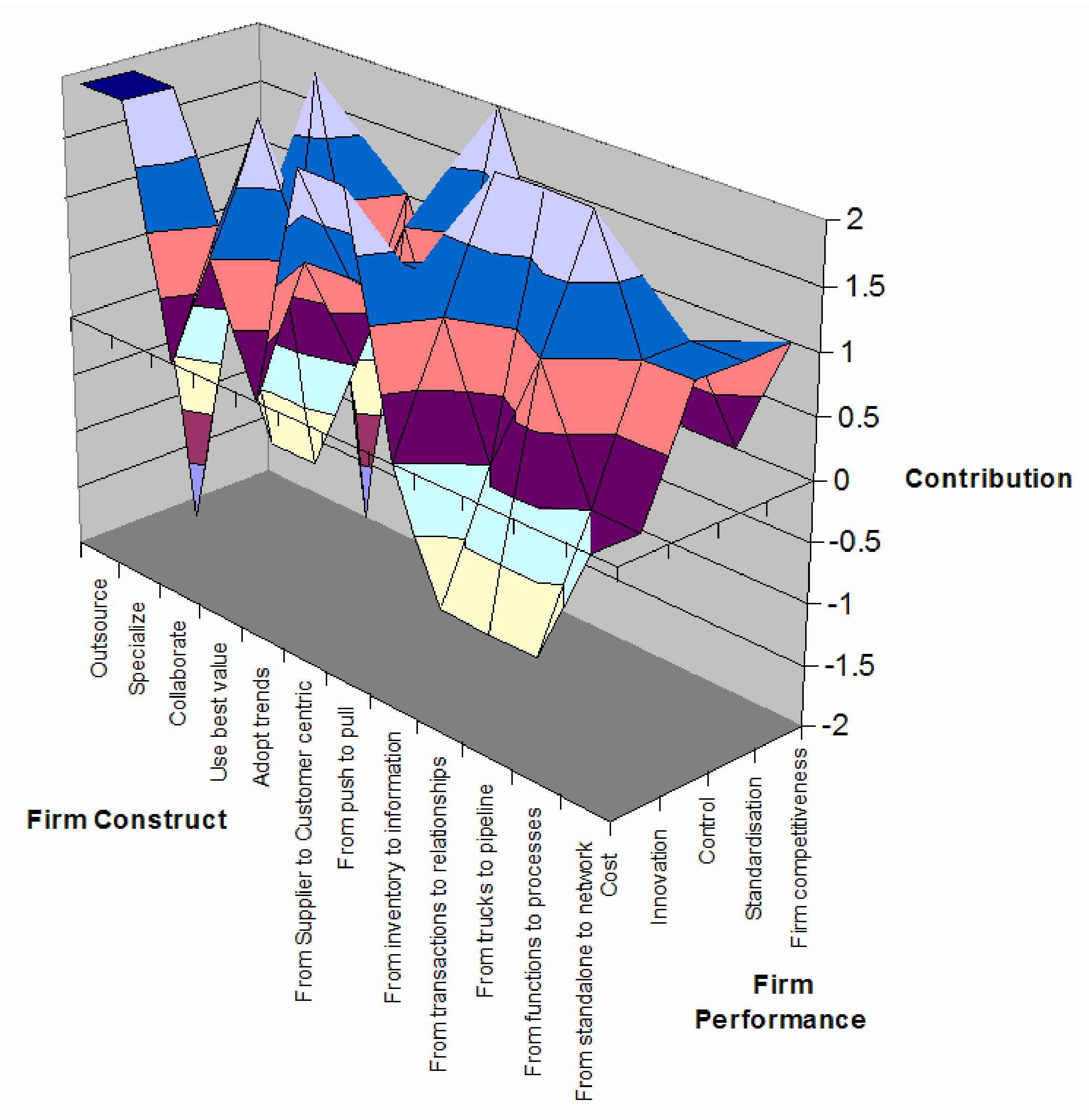


Figure 3-7 Firm constructs showing effects on firm emergent properties

Figure 3-7 shows the positive or negative effect of each firm construct upon the firm itself. This reflects the column 'How does it affect the Firm', the final column of Table 3-4. Firm constructs are shown on the horizontal axis in the same order as they appear in this table. The difference in volume between the two charts shows that there is less effect (both positive and negative) from the same firm constructs upon emergent properties of the firm. These emergent properties are costs, innovation, control, standardisation and firm competitiveness. Here for example, outsourcing improves innovation having a positive effect upon the firm.

Supply network (or inter-firm) constructs are derived largely from Cooper, Lambert and Pagh (1997) and supplemented by the literature review have been mapped to these structures following the literature review (see Table 3-5).

Inter-Firm constructs	**Owned supply chain**	**Keiretsu**	**Joint Venture or 4PL**	**Heterarchy or Network**	**Market**
integrated behaviour	yes	yes	yes	yes	somewhat
mutual sharing of information	implicit	implicit	implicit	yes	no
mutual sharing of risks and rewards	no	no	yes	somewhat	no
same goal	no	no	implicit	somewhat	no
process integration; workflow / overcoming functional silos	somewhat	no	yes	preferred	perhaps
long term relationships between partners	no	yes	no	yes	no
small numbers of partners	yes	no	yes	preferred	no
antecedents (trust, interdependence, etc)	no	yes	yes	yes	no
organizational compatibility	no	no	somewhat	yes	yes
organizational complementarity	no	no	yes	yes	no
systems integratedness	somewhat	somewhat	yes	preferred	perhaps

Table 3-5 Inter-Firm Constructs affecting the supply network

A factor analysis of Table 3-5 data using a five point likert scale and using varimax rotation within SPSS software, is presented in Figure 3-8.

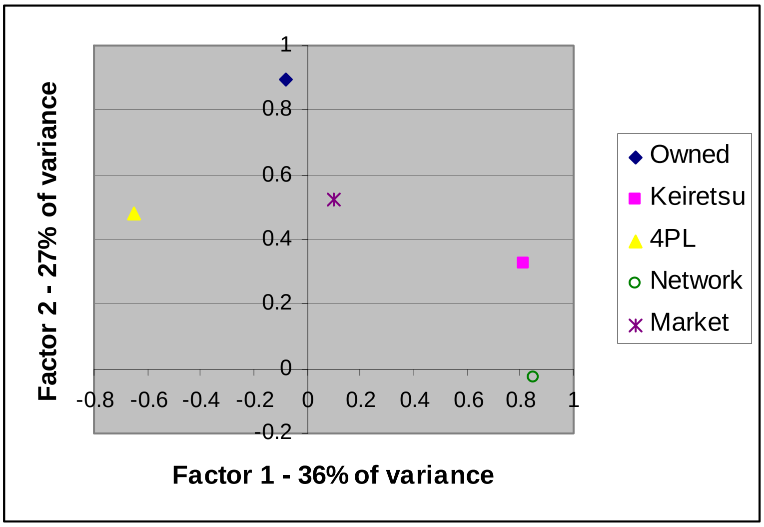


Figure 3-8 Factor Analysis of inter-firm constructs showing effects on structure

63% of the variance in the 5 types of structure is explained by 2 factors. Equal weightings are used for all constructs. The Owned and the Market archetypes are largely uninfluenced by Factor 1. The Network is uninfluenced by Factor 2. The Keiretsu and the 4PL are at polar ends of Factor 1.

3.3.5 Coevolutionary dynamics of supply networks

The dynamic network view considers the firm's position in the network, how the network evolves and how new networks are created (Mills et al., 2004). The evolution of networks occurs in a number of ways: by consolidation into fewer members (Interavia, 1993); addition of new entrants; increased outsourcing (buy as opposed to make) of non-core competences (Prahalad and Hamel, 1990), particularly to specialists (Snow and Miles, 1992), during times of rapid market growth.

The dynamic network as a typology was raised in management science in 1986 (Miles and Snow) and extended Miles's typology of Defenders, Prospectors and Analyzers to a fourth type. A major feature of the dynamic network is its ability to assemble and re-assemble via the use of brokers, flexing to meet complex and changing competitive conditions; vertical disaggregation was implicit. Market mechanisms in the form of contracts distinguished it from the use of traditional planning controls. Information systems for the use of full disclosure to members and their verification are evident. The dynamic network is reactive to the performance of its members, maximizing specialists and accommodating variety.

Where the firm is loosely connected to a network (Webster (Jr), 1992) it can leave a supply network or can be replaced easily. Once a product/model is established, the firm producing a critical system is locked in to a supply network (Gulati et al., 2000). The length of lock-in will be related to product/model longevity. Compared to the market, the network provides denser information channels, demands more loyalty and trust, shows a higher degree of social embeddedness and is more stable (MacMillan and Farmer, 1979).

Whilst the initial conditions at the time of creation of an alliance have an influence on the development of the alliance (e.g. Hamel (1991)), some alliances evolve in a punctuated equilibrium manner due to changes in the environment (Gulati, 1998) and other exogenous factors such as industry competition. Firms and the networks to which they belong are dynamic and need to adapt and combat non-linearities such as the bull-whip effect which spirals between tiers in the supply network. An action may have varying effects on different parts of the complex system resulting in varying degrees of feedback, driving virtuous or vicious cycles (Holland, 1998). Thus each firm in the supply chain directly and indirectly affects the performance of all other supply chain members as well as ultimate supply chain performance (Cooper et al., 1997) in a non-equilibrium manner. Prediction of future behaviour is difficult in a supply network, under the circumstances of heterarchical structures, multiple relationships between members with non-linear feedback.

Within the last 10 years as a consequence of globalization and proliferation of multi-national companies, strategic alliances, joint ventures and other forms of partnerships, have been found to contribute to the success of supply chains, just as Just-in-Time, Lean, Agile and similar manufacturing practices (for example, Womack (2002; 1998)) have contributed positively to performance. Daft and Lewin (1993) noted these cataclysmic changes occurring in the environment of firms with respect to networks noting there was no equivalent paradigm shift in mainstream research. They set a challenge for the development of a network theory to describe their observations of increasingly networked firms. Their call generated some 66 citations (located using Web of Knowledge (WOK) electronic database on 27/09/2006). A text analysis of the titles and abstracts of the citing articles was completed using a software package called RefViz™. Three monothetic (non-overlapping) clusters of citations are found which support a network paradigm as a new organizational form. These three clusters describe three ways of explaining the network paradigm: ecological, individual and structural. Articles in the first cluster take a macro, co-evolutionary perspective in which the network exists as an ecological systems of flexible learning firms. From the second cluster, articles focus at the individual level on behaviour and responses. These articles describe reflexivity, reciprocity and the role of social mechanisms in inter-firm relationships. The third cluster focuses on modular, open organization designs that embrace and promote network inclusion. Articles in the first two clusters highlight the need for self-organization at multiple levels. The third cluster demonstrates the ability of managers to intervene to enable (or inhibit) coevolutionary dynamics between firms.

In summary, supply network structures include: the hierarchy, the heterarchy, the market, the 4PL™ and the Keiretsu (in the Far East). Each of these network forms has appeared as a consequence of adapting to boundary conditions, consciously changing them to enable the teleological nature of the supply network. This section has taken a broad look at dynamic, evolving supply networks considering the many factors relating to the types of structure and governance which might evolve. The next section investigates the context of the commercial aerospace industry and formulates propositions relating environmental trends to supply network structures and behaviours, and to effects upon demand and the environment.

3.4 Inter-firm Characteristics

Inter-firm characteristics of commercial aerospace manufacturing supply networks were identified as one of the outcomes of a three year ESRC grant "Modelling the Evolution of the Aerospace Supply Chain" 2005-2008. This project was a continuation of the ESRC NEXSUS Priority Network. These characteristics were located in extant literature, from the public web-sites of large firms and from evidence shared by the firms who were industrial partners to the project.

The research aimed to develop an original and innovative benchmarking classification scheme for supply networks. A conceptual Cladogram of the evolution of the commercial aerospace manufacturing industry identified 78 inter-firm characteristics and 25 organizational forms. These organizational forms are the groupings of specific characteristics which distinguish one supply network form from another. The classification was achieved via systematic coding using original authors' descriptions. Saturation of the coding was reached when articles did not extend the classification scheme any further. Inter-firm characteristics fell into seven supply chain issues:

1. Co-ordination and integration
2. International and global issues
3. Relationships and power
4. Risk and resilience

5. Total quality management, and lean and agile supply chains
6. Learning and communication
7. The evolutionary aspects of change

Further details may be found in the published papers (Rose-Anderssen et al., 2009a; 2008a). As a summary, the literature which was consulted and the character states (inter-firm characteristics) are shown in Tables 3-6 and 3-7, organized by supply chain issue.

Supply chain issues	Literature	Character states
1 – Co-ordination and integration	Bales et al (2004) Goffin et al (2006) Romano (2003) Samaranayake (2005) Thomas & Barton (2007) Van Donk & van der Vart (2004)	22 - Dealing with strategic issues for the whole SC 46 - Investment in supply chain infrastructure 49 - Social co-ordination and control 52 - Intra company integration 53 - IT-system integration 54 - Inter-company integration 55 - Intra-company integration 56 - High levels of integration 60 - Open interdependencies
2 - International and global issues	Cristiano et al (2000) Emiliano (2004) Esposito (2004) Goldstein (2005) Korneliussen & Grønhaug (2003) Lefebvre & Lefenvre (1998) MacPherson & Pritchard (2002) Mattson (2003) Pritchard and MacPherson (2004) Pritchard and MacPherson (2005) Thomas & Barton (2007) Williams et al (2002)	1 - Outsourcing competitive advantage 2 - Outsourcing what is easily imitated 25 - Collaboration across national borders 26 – Political requirements 29 - Direct offsets as part of sales contract 33 – Culture and attitude focus 34 – Cultural change as adjustment to local practice 36 – Ability to handle cultural differences 38 – Knowing how to respond to the environment 40 – Appropriate relationships according to the context the firm is in 68 - Indirect offsets as part of sales contract 69 - Incorporating suppliers from customer's country
3 - Relationships and power	Cox (2004a) Cox (2004b) Giunta (2006) Goffin et al (2006) Paliwoda & Bonaccorsi (1994) Preiss and Murray (2005) Stjernström & Bengtson (2004)	3 - Investing in a high level single supplier relationship 7 - Long-term collaborative relationships 8 - Formal partnerships 10 - Supply chain sourcing – multiple suppliers 13 - Partnership sourcing 26 - Political requirements 30 - Collective channelling of competing interests into shared interests 31 - Shared domination of supply network 36 - Ability to handle cultural differences 37 - Focus on understanding the players in the supply environment 38 - Knowing how to respond to the environment 39 - Power relationship structures 40 - Appropriate relationship according to context firm is in 41 - High level of buyer dominance over suppliers 47 - Focus on internal and external relationships 59 - Suppliers collaborating on schedules and pricing 67 - Decentralised decision-making 72 - Supplier development 73 - Empowering employees to improve work processes 75 - Monitoring suppliers 76 - Online reverse auctions to drive down unit prices 77 - Commitment to cost reductions for long-term business relationships

Table 3-6 Cladistics Classification of Inter-firm Characteristics (part 1)

Supply chain issues	Literature	Character states
4 - Risk and resilience	Christopher & Peck (2004) Haywood & Peck (2003a) Haywood & Peck (2003b) Haywood & Peck (2004) Lonsdale (1999) Peck (2004) Peck & Jüttner (2002)	23 - Risk assessment for whole supply chain; market, financial and technological risks 58 - High market responsiveness through dynamic and flexible networks 62 - Open and transparent approaches to performance 63 - Focus on understanding the suppliers cost and quality systems
5 - Total quality managements, lean and agile supply chains	Cagliano et al (2004) Cristiano et al (2000) Harrison et al (2002) Kannan & Tan (2004) Korneliussen & Grønhaug (2003) Matthews (2006) Takahashi & Nakamura (2000) Womack et al (1990)	17 – Suppliers selected on basis of quality 18 - Focus on product quality 19 - Focus on distribution quality 21 - Flexibility of business operations, delivery time and costs 33 - Culture and attitude focus 34 - Cultural change as adjustment to local practice 35 - Creating a culture of continuous improvement along chain 64 - Total quality management procedures 65 - Just-in-time delivery perfection from suppliers 66 - Moving assembly line at airframe manufacturer
6 - Learning and communication	Allen (2001) Blackler (1993) Engeström (1987) Perez-Araos et al (2007) Preiss & Murray (2005) Rose-Anderssen et al (2005)	50 - Supplier customer dialogue 51 - Communication skills 70 - Focus on explorative learning within and between firms 71 - Investment in training to improve product quality, delivery time and collaboration 74 – Company performance as inter-company competence
7 – Evolutionary aspects and history	Airbus web-site (2006) Boeing web-site (2006) Allen (2001) Blackler (1993) Day & Atkinson (2005) Engeström (1987) Edgerton (1991) Fearon (1969) Fearon (1974) Higham (1968) Mentsforth (1947) Rae (1968) Rose-Anderssen et al (2005) Rose-Anderssen et al (2008) Simonson (1960)	4 - Short term goals and expectations of suppliers 5 - Arms-length, non collaborative relationships 6 - Repeated transactions 9 - Supplier selection 11 - Supply chain management 12 - Subcontracting of whole sections and systems 14 - Local purchasing 15 - Market approach to supply 16 - Suppliers selected on basis price 20 - Subcontracting easily adoptable manufacturing technologies 24 - Industry wide sharing of knowledge 27 - Division of labour, diversification of expertise and responsibility 28 - Regional clusters of expertise 32 - One off purchases 43 - Planning and control systems 44 - Organisation structures 45 - Management methods 48 - Collaborative relationships between buyer and supplier 57 - Low levels of integration 78 - Subcontracting of propulsion engines

Table 3-7 Cladistics Classification of Inter-firm Characteristics (part 2)

Eighteen distinct forms of aerospace supply chains were identified based on the interpretation of the 78 character states above. Forms 10 and 11 identify a major bifurcation point where the subsequent supply network forms have been given the number 1 or 2 according to the branch they are allocated. This made the total number of forms 25 shown in Table 3-8.

The naming convention was influenced by the most important characteristics of the organizational form and the historical context. A rule for the inclusion of characteristics was that they had shown some sustainable significance and contribution to change through some documented period.

1. Simple material transactions	14. Agile supply chains 1
2. One off purchasing systems	15. Agile supply chains 2
3. Local purchasing systems	16. Lean supply chains 1
4. WW1 governmental outsourcing	17. Lean supply chains 2
5. Arms-length supplier relations	18. Global supply chains 1
6. WW2 governmental outsourcing	19. Global supply chains 2
7. Simple supply chains	20. Global political supply chains 1
8. Collaborative supply chains	21. Global political supply chains 2
9. Modern airframe supply chains	22. Global infra structure supply chains 1
10. OEM dominated supply chains (path 1)	23. Global infra structure supply chains 2
11. Joint venture supply chains (path 2)	24. Global local subcontractor supply chains 1
12. TQM supply chains 1	25. Global local subcontractor supply chains 2
13. TQM supply chains 2	

Table 3-8 Organizational Forms in Commercial Aerospace Manufacturing

The grouping of supply network forms is based on common ancestry. This was influenced by the indication of changing characteristics in the historical accounts. A characteristic can be found in all descendants of a recent common ancestor. As new characteristics are introduced they either work well or poorly with existing characteristics and bifurcations may occur when a new bundle is significantly different from any previous bundle. MacClade (Version - 4: Analysis of Phylogeny and Character Evolution) software was used to generate the Cladistics tree shown in Figure 3-9. Time is the unit of the horizontal axis on this one dimensional chart. The Cladogram illustrates two main competitive types of supply network, one based in the West and the other in Europe.

The *OEM dominated supply chain* (original equipment manufacturer) form has for a long time been represented by traditional and American commercial aircraft production. This was challenged in the early 1970s with the introduction of *Joint Venture supply chains* when the European consortium, Airbus, entered the world market of aircraft production, following the British and French governments' joint undertaking in 1962 to develop the supersonic airliner Concorde.

The commercial aerospace manufacturing sector is today dominated worldwide by Boeing and Airbus, the commercial wing of EADS (European Aeronautic Defence and Space Company) (AIGT (Aerospace Innovation and Growth Team, DTI), 2003). This section identified inter-firm characteristics which form the basis for the empirical research undertaken in this thesis.

The next section reviews the anticipated performance outcomes or success criteria by which supply network membership might be evaluated.

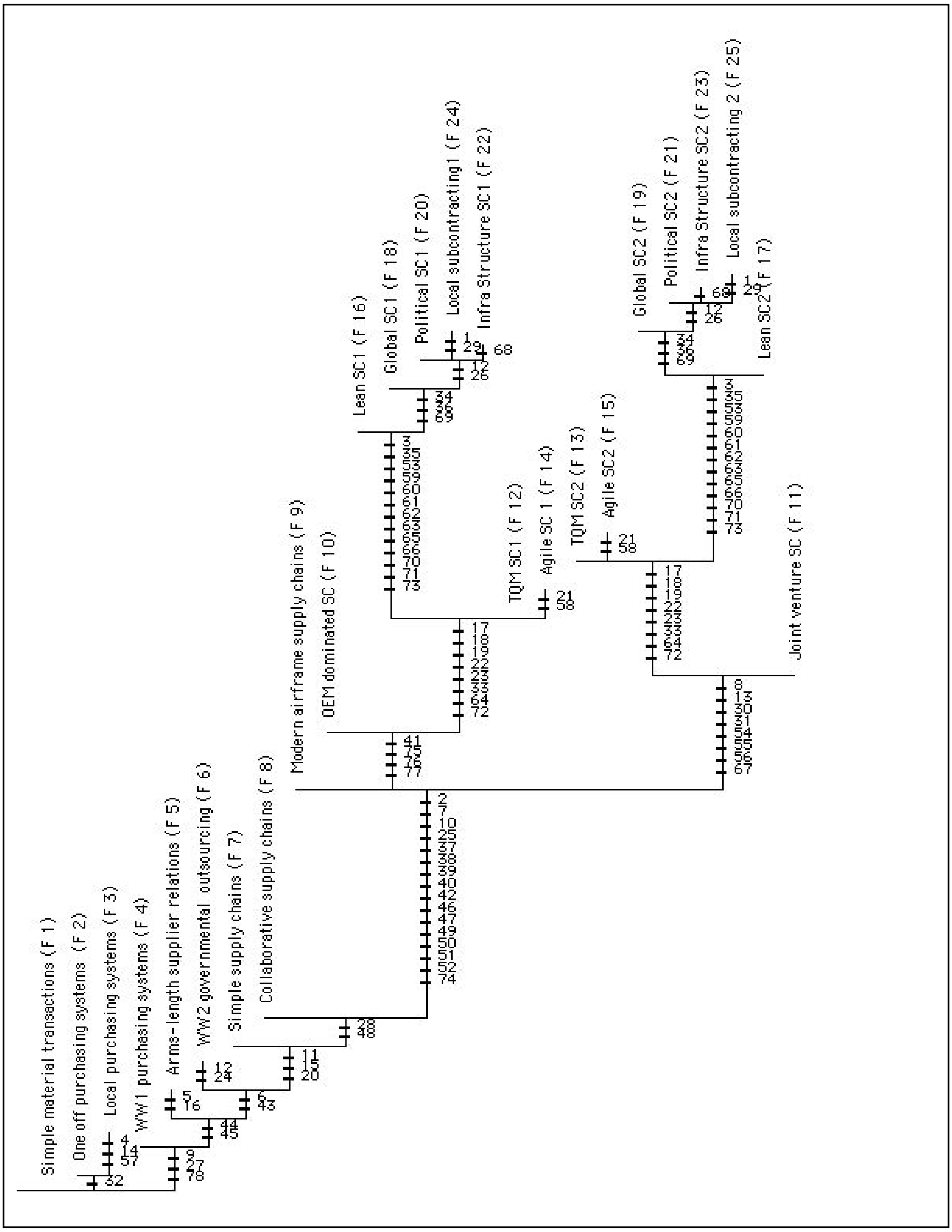


Figure 3-9 Conceptual Cladogram of Aerospace Supply Chains

3.5 Performance Outcomes

This sub-section proposes a parsimonious set of performance outcomes which accrue to firms from supply network membership.

There are three fundamental performances explicit in the purpose of supply networks: cost efficiency, high quality and delivery performance. We note how firms have learned to create higher quality at lower cost (Lee, 2005), but agility and customer responsiveness in terms of combining capabilities of efficiency, flexibility and responsiveness is key in the 2000s (Gunasekaran et al., 2002; Lloyd, 2002) to delivery performance. "*Agility enables companies to adjust quickly to shifting needs. Adaptability allows them to evolve their supply chains as environments and business purposes change.*" (Lee, 2005: 113). Agility is not about speed, as speed is a relative not an absolute concept when applied to organizational change (MacIntosh et al., 2007).

Two other essential performance outcomes are Technology Innovation capability and Vision for the Future. The ability to innovate and make use of technology is critical to on-going adaptation and agility. As most firms adapt to the use of e-commerce and information technologies (Ho et al., 2004), firms need to have inter-enterprise capabilities. Long-term supplier technological capability through supplier development and is found to effect technology innovation (Reed and Walsh, 2002). Continuous improvement programmes are aiding suppliers to prepare for higher levels of information integration, lean-buying and the future use of e-commerce (Stundza, 2000).

Training and development remain constrained by the broader institutional environment (Lloyd, 2002). However, the capacity of firms to learn appears to be limited. Ormerod (2005) modelled the life expectancy of firms under different hypotheses about their capacity to learn. He finds that the model that fits best is the one corresponding to random extinction and very little learning.

Having a vision or frame (Kaplan, 2008) for the future is critical to adaptation, assuming that the frame is simply about psychological and personal likes and dislikes which lead to decisions made for quite (hidden) and short sighted reasons.

3.6 Research Gaps in Firm and Supply Network Coevolution

Daft and Lewin (1993) described cataclysmic changes occurring in the environment of firms with respect to networks noting there was no equivalent paradigm shift in mainstream research. This was followed in 1995 (Salancik) by a request for a network theory of organization, stating some of the many outstanding research issues that a network theory should address.

The specific use of a complex systems perspective with networks and in particular supply networks commenced only in 2001 (Choi et al.) with increased literature since, see for example Surana (2005), as researchers embrace the complex systems perspective.

Levin (2002: 17) notes that *"although it is impossible to predict every detail of system evolution, broad features are knowable, by finding a mechanism that can deal with heterogeneous ensembles of interacting agents with the continual refreshment of that ensemble by novel and unpredictable types"*. Levin thus suggests that broad features are knowable. Archetypes and inter-firm characteristics are identified in this chapter. The empirical research explores further how firms understand aerospace supply networks and their coevolution with the firm. Earlier, Romanelli (1991) noted that whether change is viewed as a gradual or punctuated process most organizational models of evolution do not adequately examine the origins of novelty itself to explain how a new organizational form emerges. One of the reasons for this is that most organizational models of evolution view change as a linear process of variation, selection, retention. The proposal to use a complex systems perspective makes headway to address this deficiency.

Volberda and Lewin (2003: 2111) identify *"four co-evolutionary generative mechanisms (engines) – natural selection, managed selection, hierarchical renewal and holistic renewal – to illustrate the extensive range of evolutionary paths that can take place in a population of organizations*". They state that literature on the role of managerial intentionality in organizational adaptation is inconclusive and suggest that "*empirical coevolution research represents the next frontier for empirically solving the adaptation selection debate*" (Volberda and Lewin, 2003: 2129).

Surana et al (2005) state that one of the major challenges in supply chain management is the deployment of coordination strategies leading to adaptive, flexible and coherent collective behaviour in supply chains. They note that the hurdle has been the lack of principles that govern how supply chains arise and develop, and what is possible given the lower-level constituent entities. They propose that treating supply chains as complex adaptive systems can be exploited to characterise and model supply chain networks.

Miles and Snow (2007) identify a research gap for new models of inter-firm organization and collaboration which can exploit knowledge. We attempt to address these gaps with modesty, because in taking a complex systems perspective, we are aware of the limits of knowledge (Allen, 2001b) and predictability within the supply network. Knowledge within the ecological perspective is co-evolutionary, stochastic and becoming (Tsoukas and Chia, 2002); it is difficult to measure, based in value judgments thus subjective, and certainly not neo-classical, mechanical nor predictive.

3.7 Summary

This chapter has reviewed the literatures on firm evolution and on supply network evolution. For the former, it has described alternative ways of classifying firms, using typologies and organizational forms. The coevolutionary dynamics of firms leading to adaptation and evolution have been examined. Limitations to using the firm as the unit of analysis were discussed. For the latter, a history of supply network perspectives were presented, followed by a description of supply network relationships and known supply network archetypes. An analysis was completed connecting firm characteristics to supply network archetypes. This has addressed research question Q1b: “*What network structures are evident*?”

This preparatory work led to the identification of 78 inter-firm characteristics. This has addressed research question Q1c: “*What are the characteristics involved in coevolutionary change*?” In addition, the notion of performance success criteria was developed, whereby firms adopt specific characteristics and inter-firm characteristics in order to achieve performance success. Finally, specific gaps in the literature relating to firm and supply network coevolution were identified.

The next chapter undertakes a literature review of evolutionary theory and coevolutionary theory. It extends the introduction in Chapter 1 whereby the rationale for a complex adaptive systems perspective was introduced. It demonstrates the applicability of these theories to explaining the coevolutionary dynamics of supply networks.

4 THEORETICAL FRAMEWORK

Because evolution selects for populations with sub-optimal current performance, this in turn allows greater micro-diversity by a reduced selective pressure. "Furthermore, we show how the mechanism of variability itself could be adjusted by the evolutionary process itself, leading to the idea that evolution is driven by the noise to which it leads."

(Allen and McGlade, 1987: 737)

This chapter sets out the theoretical, metaphysical and conceptual frameworks that will be adopted in this thesis. It is organized into a number of sections as follows. The first section provides a history of evolutionary theory and sets out its applicability to socio-economic systems. The second describes the development of coevolutionary theory which extends evolutionary theory to incorporate mutual adaptation within a particular environment. Section three unfolds complex adaptive systems thinking and demonstrates why this particular lens adds more value than any other when examining the coevolution of two systems in the same environment. The fourth and fifth sections set out the research philosophy and conceptual framework for the research study respectively.

"Organization theories attempt to capture a multi-faceted reality with a finite internally consistent statement but are essentially incomplete. A good theory is by definition a limited and fairly precise picture. It does not attempt to cover everything and would fail to meet the parsimony criterion if it did. Scope conditions are one means of expressing the limitation. Also, assumptions and explanatory principles…Theories always constrain the theorist's field of vision – one of the canons of good theory construction is to recognise these limitations. But as the theorist focuses, tests, revises, defends, the theorist develops a 'trained incapacity' to appreciate aspects not mentioned in his or her theory" (Poole and Van de Ven, 1989: 562). To avoid this incapacity, wherever decisions are taken within the research design and implementation, limitations are identified.

4.1 Evolutionary Theory

There has been a long tradition of applying Darwin's Theory of Evolution or more correctly neo-Darwinism to explain the constitution and processes underlying evolutionary change in firms.

This section has two sub-sections. The first provides a brief history of evolution from biological science since the origin of evolutionary theory rests in the natural sciences. The second sub-section describes the application of evolutionary theory to theories of growth and change of firms in organization and management science.

4.1.1 History of evolution in organic biology

Traditional evolutionary theory is based on Darwin's Origin of Species (1859) and Newtonian deterministic premises. The argument is that there exists variation in a population and that the favoured races are preserved with respect to the environment in the struggle for survival. Darwin identified the laws for evolution: reproduction, inheritance, variability between individuals and the struggle for existence.

Many scholars rejected Darwin's theory of evolution as it was seen as denial of religion or godly intervention. As a result, the ideas of Lamarck (1984) resurfaced. Lamarck had proposed inheritance of acquired characters through their use and disuse in his treatise some 50 years earlier and so neo-Lamarckism was invented. The approach that intervention could improve the characteristics of a being was more attractive than change through competition and nature selection (Jablonka and Lamb, 2005). Lamarck discussed the influence of the environment on the activities and habits of animals, and on the influence of the activities and habits of these living bodies in modifying their organization and structure (UCL, 2008).

In 1866, Mendel (1930) proposed two principles of heredity from observation of the characteristics of pea plants. The first was the Law of Segregation which said that characteristics of the offspring derived from both maternal and paternal factors. The second was the Law of Independent Assortment which said that characteristics can be independently inherited from mother and father.

Neo-Darwinian Theory was constructed proposing that each daughter cell receives only half of the parent cell's chromosomal material (Weismann et al., 2007). This theory on the sharing of parent genes was later adopted into the new science of genetics along with Mendel's ideas. Weismann's rejection of the heritability of acquired characteristics was also accepted but this became a key differing point in the understanding of evolution. Lamarckians disagreed with Weismann but could not show how acquired characteristics became heritable.

Darwinism itself then came under challenge as it could not explain the observed jumps in populations. Darwinism was based in the notion of gradual evolution through selection of small variations. This issue of discontinuous evolution became an important topic. De Vries (1911) proposed that mutation, a process without cause, irreversibly changed germ plasm, causing saltation, a big jump in generations of evolution. This process was later refuted.

4.1.1.1 The modern synthesis

The gene as the conceptual basis of heredity was proposed in 1911 by Johannsen. He differentiated between genotype, the pool of genes which is inherited, and phenotype, the observed characteristics (of a plant in the case of his research). The phenotype was influenced by environmental conditions and so characteristics of the phenotype can only be inherited if they are the result of differences in the genotype (Johanssen, 1911).

Dobzhansky devised the 'Modern Evolutionary Synthesis' (Dobzhansky, 1982) building on Darwin's evolutionary theory and Mendelian's genetics but rejecting Lamarck's heritable acquired characteristics and de Vries's mutation thesis. This synthesis covered 1) heredity: transmission through germ-line germs 2) variation (random combinations of alleles so new variations are the result of accidental changes) and 3) selection (between individuals with phenotypes that make them more adapted to their environments than others, increasing their alleles in the population)

(Jablonka and Lamb, 2005). Dobzhansky defined evolution as ‘a change in the frequency of an allele within a gene pool’. Mayr (1944) proposed a new description for species: it should not be just a group of morphologically similar individuals, but a group that could breed only among themselves. He proposed that isolated sub-populations would become different from the population as a result of genetic drift and natural selection, evolving into new species. An update was proposed to revise The Modern Synthesis of evolutionary biology by the inclusion of sociology (Wilson, 2000). Sociobiology was defined as the ‘the systematic study of the biological basis of all social behavior’ but criticized for its narrow perspective of biological destiny. In more recent time, Gould (2002) finds that the ‘modern synthesis’ has hardened into a dogma stifling science.

Although dominant and recessive genes had been conceptualized by Dobzhansky, it wasn’t until molecular neo-Darwinism in 1953 when Watson and Crick decoded the double helix structure of the DNA molecule and how it encoded amino acids into proteins via Messenger RNA (see Figure 4-1).

Figure 4-1 Elucidation of structure of DNA by James Watson & Francis Crick

The gene, the unit of heredity, became known as the DNA sequence. The DNA sequence might code for a protein or RNA molecule. In higher organisms, heredity units were later found to exist outside the nucleus, in cytoplasmic organelles called mitochondria and chloroplasts. Mutations were understood as rare mistakes during DNA replication.

4.1.1.2 Natural selection and cooperation

Maynard Smith (1969) created a generalized set of properties that any group of entities and their world must have in order for evolution by natural selection to occur:

- Multiplication – an entity can reproduce to give two or more others
- Variation – not all entities are identical
- Heredity – like begets like – if there are different types of entities in the world, the result of the multiplication of entity of type A will be more entities of type A, while the result of the multiple of entity B will be more of type B
- Competition – some of the heritable variation affects the success of entities in surviving and multiplying.

If all these conditions are met, evolution by natural selection is inevitable: the type of entity that has the greatest ability to survive will increase in frequency. Eventually evolution in this world will stop because all the entities will of the same type. However if heredity is not always exact, so that from time to time new variants arise then variations in a certain direction may accumulate and produce a complex functional system. And of course today we know that heredity is not always exact. Mutations, which exist in various forms, alter chromosomal material and create variation in the gene pool (Maki, 2002).

Research on cooperation by individuals Hamilton, Williams and Trivers noted that some individuals behaved in a way that benefited their group although the behaviour did not benefit or was at a cost to the individual; the group of beneficiaries appeared to have inherited the same genes (Workman and Reader, 2004). Dawkins (2006) took this up, extending in particular Hamilton's work and proposed a gene-centric view that could explain adaptive traits proposing that the existence of selfish genes enhance the chances that the gene is present in greater quantities in the next generation. Thus there would be competition between genes (themselves known as replicators), since the gene is inherited and so selected in the population. In addition, heredity and variation cannot be influenced by adaptive process in the individual (referred to as a vehicle) and so Dawkins denies Lamarckism. There is also a proposal for a 'meme', a cultural unit of information and a replicator (Dawkins, 2006).

Gould (2002) disputes Dawkins, insisting that selection occurs among individuals, groups or species, not genes. Mayr (EDGE, 2001) concurs that the idea that 'the gene being the target in selection is completely impractical'. He continues to explain that the whole genotype of the individual is the target of selection, and that Darwinian Theory still holds with this single revision. All agree nevertheless that genes are the only unit of heredity and that acquired characters can not be inherited.

4.1.1.3 Transitions and inheritance systems

Eight major transitions are identified by Maynard Smith and Szathmáry (1995) shown in Table 4-1. The stages are described as evolutions of complexity and are limited to the way in which information is transmitted between generations; excluded are major phenotypic changes, e.g. the conquest of land by plants and animals.

Complexity is measured by Maynard Smith and Szathmáry in terms of the coding DNA of the organism, rather than the genome size. They conclude that more complex organisms require lengthier instructions. The notion that organisms become more complex by 'a force that perpetually tends to make order' arose from Lamarck at the beginning of the 19th century. The question of whether or not more complexity is progress is another matter. In any event, all transitions share a number of common properties which help us understand these transitions (Maynard Smith and Szathmáry, 1995):

Transition from	Transition to	Comment from book	Observation
Replicating molecules	"Populations" of molecules in compartments	Can't observe	
Independent nucleic acid molecules - replicators (probably RNA)	Chromosomes (linked molecules)	RNA world hypothesis; Linked molecules replace together after the transition	
RNA as both genes and enzymes	DNA as genes; proteins as enzymes	DNA + protein as genetic code	
Prokaryotes (uni-cellular organism without a nuclear membrane or discrete nucleus or other specialized compartments within the cell).	Eukaryotes (may be single or multi-cellular, but contains a distinct membrane-bound nucleus)	Can observe, The ancestors of mitochondria and chloroplasts were once free-living prokaryotes: today they can replicate only within a host cell	Bacteria are prokaryotes
Asexual clones	Sexual populations	Evolution of sex	Asexual reproduction is relatively rare among multi-cellular organisms. Hypotheses are that sexual reproduction offers rapid generation of genetic diversity allowing adaptation to changing environments.
Protists (unicellular organisms)	Multi-cellular organisms – fungi, plants, animals	Cell differentiation	Bacteria are protists The cells of animals, plants and fungi are descended from single-celled protists, each of which could survive on its own. Today they exist only as part of larger organisms.
Solitary individuals	Colonies with non-reproductive castes		An example of such a colony is a bee-hive, with worker bees, queen bee
Primate societies	Human societies (language)	Socio-cultural evolution	Evolution responding to the need to cooperate

Table 4-1 Eight major transitions in Evolution - Maynard Smith and Szathmáry (1995)

1. Smaller entities come together to form larger entities
2. Smaller entities become differentiated in the larger entity
3. Replication of the smaller entities is possible usually only via the larger entity, because the larger entity emerged with stable mechanisms preventing its disintegration into smaller entities.
4. Smaller entities can disrupt the development of the larger entity
5. New ways to store, transmit and interpret information have arisen

Maynard Smith and Szathmáry give primacy to the aggregation of entities into new coherent structures for survival whereas most evolutionary theorists focus on the struggle for survival and replication. Capra (1996) provides five basic principles of ecology needed to foster systemic survival: 1) the connectedness and interdependence of members, 2) the recycling of resources, 3) the partnership and cooperation needed for adaptation of multiple species; 4) adjustment in response to constant feedback and 5) pluralistic resilience by the provision of diversity. See table 4-2. This ecological perspective helps to understand things systemically means putting them into context and establishing the nature of their relationships. Capra (1996) contrasts the movement from traditional view to the systems view – parts to whole, mechanistic or organismic, atomistic to holistic, reductionistic to ecological.

Principle	Description
Interdependence	All members of an ecological community are connected in a vast and intricate network of relationships, the web of life via multiple feedback loops that create non-linear patterns of response
Cyclical Flow of Resources	Nutrients are recycled so that the waste of one species becomes food for another, or conversely, the outputs of one market-driven entity may threaten the survival of another
Partnership and Cooperation	In co-evolution in which the adaptations of multiple species are mutually interdependent
Flexibility	Continual adjustment to feedback in response to constantly changing conditions
Diversity	Involving pluralistic resilience in the sense that a "diverse ecosystem" tends to contain "many species with overlapping ecological functions that can partially replace one another".

Table 4-2 Principles of ecology for systemic survival (Capra, 1996)

Our final foray into biological evolution ends with a look at types of heredity system. Jablonka and Lamb (2005) recognize four inheritance systems, each of which she defines as a dimension of evolution and allows phenotypic (environmentally influenced as well as genetic) variations to be transmitted between generations. The first is genetic (DNA) inheritance and is already discussed in this chapter. The second is **epigenetic** inheritance and includes differences in specialized cells, structural inheritance, e.g. prions, chromatic-marking system and RNA interference. The primacy of epigenetic processes, rather than gene sequence and gene expression changes, in morphological origination is proposed by Müller and Newman (2003) as more comprehensive theory of evolution.

Jablonka and Lamb's third heredity system is **behavioural** inheritance, including learning as a result of experience. The fourth is **symbolic** inheritance and encompasses cognition, communication, language and other types of symbol. This symbolic inheritance system is self-referential and has to be taught, being a new dimension of reality (Cassirer, 1962). The symbolic framework is not memeticist (al la Dawkins) nor neo-Darwinian but Lamarckian, embedded in historic development. Further, the evolution (and destruction) of civilizations is charted and ascribed to cultural rather than genetic evolution (Ehrlich, 2002).

The four types of inheritance system are compared in terms of variation processes, shown in Table 4-3. Except for Generic Inheritance, variation is thus targeted, subject to filtering and modification during development and changes the selective environment. It is only with Symbolic Inheritance that variation is constructed through direct planning.

Jablonka and Lamb (2005) propose that variation is no longer random or blind to function; the variants inherited and the final form assumed, will depend on the filtering and editing processes which occur before and during transmission. So variation arises for a purpose, it is teleological and Lamarckian.

Inheritance system	Variation is targeted (biased generation)?	Variation subject to developmental filtering and modification?	Variation constructed through direct planning?	Variations can change the selective environment?
Genetic	Generally not	Usually not	No	Only insofar as genes can affect all aspects of other inheritance systems
Epigenetic	Yes	Yes	No	Yes
Behavioural	Yes	Yes	No	Yes
Symbolic	Yes	Yes	Yes	Yes

Table 4-3 Comparison of 4 forms of inheritance system (Jablonka and Lamb: 2005: p236)

Heritable variation may arise in response to environmental change. With respect to the 'evolution mountain' of new types of inheritance system (Jablonka and Lamb, 2005) underlying new types of organism, the question arises as to whether the inheritance systems, through which variations arise, already exist. Jablonka and Lamb refer to the great evolutionary transitions, built on new types of information transmission, the emergence of new types of organisms, the importance of existing inheritance systems changed.

This section has looked at the history of evolution in the natural sciences, now extending into social sciences, cultures and economies. In summary, a number of key notions are extracted.

1. An individual's chromosomal DNA is inherited from its parent(s)
2. The process of variety creation is stochastic (or blind) not teleological (purposeful)
3. Acquired traits are heritable (the Lamarckian view of use-inheritance)
4. Saltation, or punctuated change, is caused by mistakes in replication
5. Organisms become parts of more complex organisms, compromising their ability to replicate outside the new host but continuing to influence the complex organism
6. Stable mechanisms emerge preventing the disintegration of the larger organism

7. The set of coding instructions for replication of the more complex organism is more lengthy and presumably prone to more error than the simpler organism
8. Individuals in a group cooperate for the benefit of their group at their own expense
9. Adaptation via sexual reproduction is faster at creating diversity than asexual reproduction, increasing the probability of selection in a changing environment
10. Competition and selection occur at the individual, group or species level, not at the gene level
11. It is not generally true that progress is a universal law of evolution

The next subsection reviews the application of evolutionary thinking to firms.

4.1.2 Application of evolution to firms

The earliest theorist to embrace evolution was Herbert Spencer, who developed a conception of evolution as 'the progressive development of the physical world, biological systems, the human mind, and human culture and societies', thus bringing evolutionary theory to sociology. He coined the phrase "survival of the fittest" in *Principles of Biology* (Spencer, 1868) after reading Darwin's Origin of Species. Spencer stated that "all structures in the universe develop from a simple, undifferentiated, homogeneity to a complex, differentiated, heterogeneity, while being accompanied by a process of greater integration of the differentiated parts." He suggested this universal law of the evolution of complexity applied everywhere in the cosmos. The primary mechanism for the transformation of species that he recognized was Lamarckian use-inheritance, i.e. those organs developed by use would result in changes transmitted to the next generation. In contrast to Darwin, he proposed a direction and even a final state of evolution in equilibrium.

Campbell, a social psychologist, (1969) introduced the concept of Blind Variation and Selective Retention (BVSR) in socio-cultural knowledge evolution. He re-awakened Darwinian selectionist theory into social science (McKelvey, 1999b). Nelson and Winter (1982) brought evolutionary theory to economics using it as a dynamic process over time and substituting routines for genes, search for mutation, and selection via economic competition. Key contributions of evolutionary thinking, populations and the environment were brought to organization science by Aldrich (1979) and McKelvey (1983).

The essential points made in these early papers (McKelvey, 2004a) were that

1. Genes replicate with error
2. Variations are differentially selected which alters gene frequencies in populations
3. Populations have differential survival rates given existing niches
4. Niche emergence and genetic variance coevolve
5. Struggle for existence

At the same time, many organizational scientists developed a dominant theme in theories of organization by emphasizing the relationships between firms and their environments. Hannan and Freeman (1977) introduced us to Population Ecology. These approaches work on the fundamental principle of incremental, micro, slow change creating and renewing observable macro structure. The diversity of organizational forms is generally explained by appealing to the diversity of the environments in which organizations operate (Hannan and Freeman, 1977; Lawrence and Lorsch, 1967). Lawrence and Lorsch (1967) developed structural contingency theory, Meyer and Rowan (1983) introduced institutionalization theory; Pfeffer and Salancik (1978) developed resource dependence theory, and so on. The broad argument of these theorists was that firms tend to become isomorphic with their environments through processes of adaptation and/or selection. Theories were developed in the study of organization change in relation to exogenous environmental change. Organizational ecology (Hannan and Freeman, 1977) for example focused on the environment as the principle source of competitive advantage, ignoring the effect that firms had in shaping the selection environment

The influence of the firm on the environment and how the environment (defined as other firms and populations) influences these firms was thus largely ignored (DiMaggio and Powell, 1983). Nelson (1996) warns that neglecting how environmental factors interact with the firm, will lead to a lack of progress understanding industrial leadership. But the causal mechanisms that produce particular behaviours in firms remain constant in evolutionary explanations and not the behaviours themselves (Tilly, 1997). The same causal mechanisms can lead to different behaviours because the environment is never exactly the same.

With the environment in mind, many theorists have used the concept of adaptation to the environment as a core requirement for firms. Ashby (1960) suggests that adaptability is enhanced among the system's components if there is a modest degree of interaction among the system's components. In what Ashby terms, a fully joined system, a perturbation in one variable requires adjustment in all other variables of the system, making adaptation improbable (Glassman, 1973). Perrow (1984) makes a similar argument when analysing the possibility of "normal" accidents in complex, tightly coupled systems. Tightly coupled firms can not engage in exploration without foregoing the benefits of exploitation. In contrast loosely coupled firms (Weick, 1979) can exploit the fruits of past wisdom while exploiting alternative bases of future viability (Levinthal, 1997). With more complex interactions, it is less likely that established firms are able to respond effectively to changes in the environment.

Conventional wisdom that Darwinian selectionist processes drive out less fit firms, facilitating the 'survival of the fittest', is challenged by Kauffman (1995a) who suggests that complexity may thwart selectionist effects under some circumstances. Kauffman (2000) further argues that Darwinian Theory is equilibrium bound and is not adequate for explaining most of biological dynamics.

This brings us to the notion of dynamics being not gradual but punctuated with periods of apparent stability in-between (Eldredge and Gould, 1972). There is a shift to the study of how fast-motion dynamic heterogenous agents create order thus a movement away from slow-motion Newtonian classical physics. The process of continual change within firms, including founding, disbanding, growth and change are examined with the environment in mind (Winter, 1990).

Levinthal (1997) noted that it was inadequate to assume that there existed a well-defined mapping between the firm and the environment, noting that in reality there are likely to be a number of local optima with nearly equivalent performance. The fitness landscapes framework has been used to describe the morphology of organizational fitness by explaining a variety of phenomena: dominant designs and technology evolution (Kauffman, 1995a; Kauffman and Macready, 1995), organizational adaptation (Levinthal, 1997), 'complexity catastrophes' given the interdependence of firms' value chains (Hannan and Sorenson, 1997; McKelvey, 1999a) and the fit of archetype and strategy/leadership design in different environments (Maguire, 1999). The fitness landscape framework allows firms to be characterised by a string of variables, however, each variable has a binary on/off setting and so simplifies reality greatly.

The examination of network change in some previous studies has considered the environment. Examples include, the ways in which both exogenous and endogenous forces shape how networks evolve over time (Gulati et al., 2000) and how environmental issues are now perceived by practitioners as another component for integration into supply chain management rather than as constraints (Lamming et al., 2001). Network studies have analysed structural characteristics (network density, structural holes, structural equivalence, firm location) (Gulati et al., 2000) and profitability of industries and firm, plus network and firm level change (Koka et al., 2006). These studies are beginning to contribute to the understanding of supply chains as dynamic networks of competitiveness. In strategic management and in contrast to earlier work, Porter (1991) works to integrate theories of both environmental and firm factors into a comprehensive framework.

In his study of the global dye manufacturing industry, Murmann (2003) finds three requirements for the use of evolutionary explanation:

1. to introduce novelty into the economic system, a mechanism must exist to create variants of existing structures
2. selection pressures need to be consistent, so new variants need to be created more frequently than new selection criteria otherwise the evolutionary process would not bring about new trial and error structures that are better adapted
3. a retention mechanism must be present that transmits economic structures from the present to the future, otherwise new developments could not build on previous adaptive achievements.

This is broader than the Darwinian formulation of biology as the latter is a special case in which variations are random, not guided by previous experience.

The demise of firms from an evolutionary point of view is undesirable unless brought about by other firms which provide better products and services. Schumpeter's (1942) process of creative destruction in a capitalist regime underlines the evolutionary view that better economic structures can only be achieved by allowing underperforming entities to be replaced by organizations that can make better use of their resources. Ideally surviving firms should learn from the mistakes that the failed firms made (Metcalfe, 1998). Metcalfe adds that public policy makers have a role in deciding whether to protect economic diversity and mechanisms that generate novelty in the economic system, supporting temporarily underperforming firms or infant industries. Arthur (1994: xx) perceives the economic world as one of constant transformation: "*a world where dynamics, not statics, are natural; a world of evolution rather than equilibrium; a world of probability and chance events. Above all, it is a world of process and pattern-change*." Schumpeter describes transformation arising from within the socio-economic system, driven largely by the adaptive development of firms (Metcalfe et al., 2006).

This ends the sub-section on the application of evolutionary theory to firms and makes the following points:

1. All structures move from simple, undifferentiated, homogeneity to a complex, differentiated, heterogeneity, while being accompanied by a process of greater integration of the differentiated parts.
2. Evolution is dynamic
3. Firms have routines not genes
4. Firms tend to become isomorphic with their environments
5. Interactions between firms and their environments influence the ability of the firm to exploit and explore
6. Selection processes do not always drive out the least 'fit' firms
7. Mechanisms must exist to create variants of existing structures
8. Selection in the environment runs at a slower rate than the rate at which new variants are created
9. Retention mechanisms must exist to pass on existing variants to new structures

This section has introduced some new concepts including that of open systems, feedback, and transformation driven from within. Evolutionary thinking encompasses not just the simple organism metaphor (Morgan, 1997) but an holistic, dynamic and contextual position better able to explain and describe the fundamental nature of economic systems. The next section introduces coevolutionary theory, looking in more depth at the mechanisms driving change.

4.2 Coevolutionary Theory

"*One of the more important post-Aristotelian developments in evolutionary theory is the emphasis on endogenous environments, on the ways in which the convergence between an evolving unit and its environment is complicated by the fact that the environment is not only changing but changing partly as part of a process of coevolution. There is mutual adaptation between the unit of evolution and the environment*" (March, 1994: 43).

This subsection attempts to show that coevolutionary theory is an advance over existing theories because it focuses expressly on how competitive leadership positions are gained and lost over time. Unlike a static theory an entity need not start with a significant lead in order to possess a large leadership in market share after a long period (Murmann, 2003). Coevolutionary theory explains how industrial leadership is gained or lost in a process of mutual adaptation. For coevolution to occur there must be reciprocal adaptation between the entities that coevolve.

This process of mutual adaptation is at the heart of coevolutionary theory. There is no single cause-and-effect, as the entities involved adapt to each other and to the other entities within their population. Evolution in this context is concerned with change that could be described as qualitatively different, revolutionary, or faster than the speed of change in the environment (Ashby, 1962). Traditional approaches to the study of change in firms are based in a deterministic, predictive research paradigm, such as Hage's (1980) 'structure-functionalism', Bhaskar's (1979) critical realism or Burrell and Morgan's (1979)'functional sociology'. These approaches can produce meaningful insights for mature firms, where environments are relatively static and where innovation is modest, but they do not offer a satisfactory description for a number of reasons.

4.2.1.1 Reasons for using coevolutionary theory

First, continued globalisation and the availability of transport infrastructure and electronic communications extend the reach of even modest sized firms into markets and resources not previously available, thus opening up greater possibilities of change from the environment. Evolutionary processes of variation, selection and retention (Darwin, 1859) operate at many levels in the economy or the set of all firms in the environment. The lowest unit is perhaps the individual sole-trader, but in the economy of trading vehicles producing jet-liners, the scope narrows to the larger firms that are located across the globe.

Second, equilibrium is transient if it exists at all, so locating and maintaining a position within the economy that bestows competitive advantage may be very short-lived. The Resource Based View (RBV) of the firm provides an explanation of sustainable competitive advantage, which is defined as a *"value creating strategy not simultaneously being implemented by any current or potential competitors and when these other firms are unable to duplicate the benefits of this strategy"* (Barney, 1991: 102). This implies the identification of a market niche that a firm can either create or exploit in a way which gives it advantage over its competition. In evolutionary terms this equilibrium does not last forever. Competitors find ways to imitate the firm or re-shape the niche to their own advantage. In a changing environment, sustainable competitive advantage needs to reflect the rate at which the firm can identify new niches, exploit them and then adapt to the next niche, and so on as the environment continues to change.

Third, a firm does not exist in isolation. It is nested within other bodies, including partnerships, regional economies, nations; and a firm itself has multiple nested sub-systems, including functions, divisions, teams, projects, individuals; and individuals belong to multiple systems, professional bodies, academic associations, social and leisure groups, etc. No entity acts in isolation. In his poem Meditation XVII, John Donne (1572-1631) wrote "No man is an island, entire of itself" echoed today in

Networks theory by Barabási (2002: 7) who states "*nothing happens in isolation*". Also, firms need to develop lobbying capabilities to shape the institutional environment in their favour (Murmann, 2003). Institution denotes "*actions, rules, social structures, and practices that persist over time and are features of social aggregates that are larger than a single organization*" (Murmann, 2003: 204).

Williamson's (2000) four-level typology of institutions demonstrates that firms can only change those institutions that experience a change during the lifetime of an industry. Many industry-specific regulations can be changed much more readily and frequently than can features of the institutional environment. If an institutional feature applies to a wide variety of industries, then coalitions are required than span across industries, in order to effect change.

Fourth, organizational investments are crucial to survive in an industry that constantly produces new products and processes because they allow firms to add new skills to their accumulated knowledge base and raise the bar for their competitors (Murmann, 2003). Further the balance of product and process innovation within the firm has a fundamental bearing on its ability to evolve. Continued investment in process efficiencies to meet market demands without adequate investment in product innovation ultimately means the death of the firm. Firms need to experiment (Allen, 1988) and adopt a fast pace of technological innovation (AIGT (Aerospace Innovation and Growth Team, DTI), 2003). The "eco-historical regime" tells us that whatever local "innovations" and evolutions have occurred, they fit within the wider milieu of the social, cultural, environmental and technological of their own history (Garnsey and McGlade, 2006).

Fifth, the importance of strategy and long-term planning by the firm plays a critical role. Strategy setting is the dominant method for projecting the firm into a potential future and mapping a way to achieve that future. Many of the most successful firms have placed a strong emphasis on strategy. Strategies help decision-makers in firms to think through what the firm needs to achieve and how it can be achieved. Implementing strategies and acting strategically places a focus on the long term and the things that are essential for evolution. Strategy and strategic change are influenced by the extent to which leaders believe that it is driven by content (that is structure) and by process (MacIntosh and MacLean, 1999).

Strategies driven by content are influenced largely by the field of economics and focus is on management activities that aim to achieve pre-determined, optimum, rational objectives. These include 1) the Strategy-Structure-Performance school, concerned with scale, scope and form of organizations 2) the Structure-Content-Performance school concerned with position and market power and 3) the Resource-Based View and core competencies perspective. They are similar in that they make assumption about economic rationality and Newtonian concepts of equilibrium and stability.

There is however, increasing recognition of the importance of key intangible organizational attributes, such as tacit knowledge, learning and intelligence that may signal a more evolutionary view of economics. A demand exists for a new paradigm focused more on process-driven strategies, essentially challenging the fact that economic rationality should be the primary determinant of strategic behaviour. The process-driven school focuses on the extent to which strategy and change are dominated by events and activities that emerge from a wide variety of influences.

Authors have explored the relationship of strategic transformation, organization structure and innovation. Anderson (1999: 216) applies complex systems models to strategic management and concludes that this leads to an *"emphasis on building systems that can rapidly evolve effective adaptive solutions"*. Strategic direction requires environments to be managed and the reconfiguration of the organizational architecture to fit anticipated adaptation of agents. According to Tushman and Romanelli (1985) long periods of incremental change are due to inertial forces of convergence that oppose radical changes in firms due to a need to be more consistent with a given strategic orientation. They also argue that short periods of radical change can only be initiated by senior leaders who re-orient or re-create the firm by setting a new strategic orientation by making the key decisions in the inter-dependent core activity domains. This second point on radical change within the firm denies the influence of the environment to cause radical change. This is a key point discussed later.

4.2.1.2 Alternative perspectives

The alternative to taking a coevolutionary perspective is to take a conventional, single-lens perspective. Mostly these alternatives treat environmental change as an exogenous variable (Baum and Singh, 1994). Exogenous variables are economic variables independent of the relationships that determine the levels of equilibrium. But the environment has significant effects on firms. Arguably firms are determined largely by their environments; the assumption that all firms within one industry interpret the environment in a single way is false (Daft and Weick, 1984; Aldrich and Pfeffer, 1976). Managers can manipulate environmental features, for example, by political action (Child, 1972) and can change organizational designs (Goold and Campbell, 2002). Industry events can reinforce or loosen network structures (Madhavan et al., 1998) . Without the explicit inclusion of how the environment of a firm influences the firm and vice-versa, a single-lens view by definition can provide only a partial view of the evolution of the firm.

An important point to make in respect of the relevance of evolutionary and coevolutionary theory to firms is that the theories themselves have evolved as a synthesis of many other theories of change. For example, Aldrich's evolutionary theory (Aldrich, 1999) recognises and incorporates relevant organizational theories such as institutionalism, resource dependence and transaction cost economics amongst others. Tushman and Romanelli's (1985) theory of punctuated organizational change integrates perspectives from literatures on population ecology, industrial organization, strategy and organization theory.

The theory of coevolution is used in connection with evolutionary theory, and so it is used together with the processes of variation and selection, but also in connection with other concepts and theories. For example, in The Coevolutionary Process (Thompson, 1994), it is used in combination with Specialization and Geographic Structure.

4.2.1.3 Summary

In summary, there are five main reasons to adopt a coevolutionary perspective:

1. increased global competition extending the selection environment of the firm;
2. the dynamics of firms, markets and economic systems such that competitive advantage cannot be fixed;
3. the firm is nested within other systems and is itself an entity formed from other systems meaning that it is connected with others at all levels;
4. investment is needed by the firm in innovation as experimentation is critical to its competitive position;
5. strategic management provides a mechanism to help shape the future of the firm

This section introduced coevolutionary theory and described its relevance and applicability to firms, networks and market economics. The next section describes the Complex Adaptive Systems perspective.

4.3 Complex Adaptive Systems

The term "Complex Adaptive System" (CAS) refers to a system that changes constantly and organizes itself without any singular entity deliberately managing it, and one that emerges over time into a coherent form (Choi et al., 2001). Adam Smith's description of the operation of the market as an invisible hand (Smith, 1977) describes the behaviour of the market as a complex adaptive system even though at that time complexity science was not available as a discipline for Smith's views.

The body of knowledge in complexity science is inter-disciplinary, with roots in physics and biology but now in many applied disciplines, including evolutionary biology, nonlinear dynamics, psychology, artificial intelligence, statistical physics and so on. The focus of investigation is "*the interplay between a system and its environment and the co-evolution of both the system and the environment*" (Dooley, 2002: 5020). Despite some literature in the social sciences making use of the laws of complex adaptive systems (from the natural sciences) by metaphor or analogy (Morgan, 1997), many have now made the case that social systems are complex adaptive systems in their own right and that methods can be successfully applied (Levin, 2002; Byrne, 1998; Henrickson and McKelvey, 2002; McKelvey, 1997).

This section examines the fundamental laws of complex adaptive systems. The first subsection looks at the nested nature of complex adaptive systems. The second examines novelty and coevolution, and the processes by which new systems emerge. The third subsection describes adaptation and feedback. Subsection 4 looks at self-organization, emergence and macro stability. The last two sub-sections look at the role of the firm and the supply network as complex adaptive systems.

Holland (1995) defines seven basics that underlie any complex adaptive system. These are shown in Table 4-4. First is the notion of aggregation of smaller-scale entities into larger scale ones, including large-scale complex behaviours from small scale simple interactions. This is not dissimilar to Maynard Smith and Szathmáry's (1995) evolutionary transitions.

Basics	**Description**
Aggregation	The grouping of smaller-scale objects into larger-scale categories and to "the emergence of complex large-scale behaviours from aggregate interaction of less complex agents"
Tagging	The key properties of an agent that direct the actions of other agents, e.g. logos of one that trigger the purchase by another. Tags facilitate selective interaction
Nonlinearity	Multiplicative and feedback effects where nonlinear interactions almost always make the behaviour of the aggregate more complicate than would be predicted by summing or averaging
Flows	Movements or relationships among nodes (agents or processors) via a network of connections (links or associations) generally involving interactive and/or feedback effects.
Diversity	Ways in which differentiated agents fill differentiated niches.
Internal Models	Mechanisms by which a complex adaptive system implicitly or explicitly anticipates the future effects of some present action, often with implications for survival based on the selective advantage of more predictively accurate models
Building Blocks	A decomposition of complex phenomena into its essential component parts.

Table 4-4 Basics of a Complex Adaptive System (Holland, 1995)

Second is that agents in the system have tags which trigger selective interaction. Third is that the effect of interactions is non-linear so that macro behaviour cannot be predicted. Fourth is that flows occurs via the network giving rise to interaction effects. Fifth is that diversity enables differentiated agents to fill differentiated niches.

Sixth is the internal mechanisms of complex adaptive systems which anticipate future effects. Seventh is the complex phenomena arise from building blocks or components.

By contrast to the reductionist, traditional scientific approach, complexity science takes an holistic approach, in which *"everything affects everything else in a web of connections"* (George Cowan, President of the SFI[1] in Waldrop (1992: 60)).

4.3.1 Nested systems

Firms are parts of multiple systems of higher order complexity, such as networks, societies, nations, each of which exists as a complex adaptive system with its own set of properties and behaviours. Firms are macro complex adaptive systems to their parts; and the parts may also belong to other macro systems. Whilst the study of emergence is non-reductionist, it depends on being able to break-down the complex adaptive systems into component parts in order to study the interactions among the components. *"The activities of the parts do not sum to give the activity of the whole…Emergence is above all a product of coupled, context-dependent interactions"* (Holland, 1998: 121).

Evolution occurs when there is emergence at the next level of hierarchy. Elements that combine may result in a structural attractor. If the attractor is sufficiently stable and has the ability to replicate, has the latent ability to innovate and is selected within its contextual environment ("space/time binding" (Jantsch, 1983)) then there is evolution.

At any given level of organization, via a nesting of systems within systems, a complex adaptive system will be composed of lower-level micro-networks and inter-woven systems which are in turn embedded into a higher-level macrostructure (Capra, 1996; Holland, 1998; Holland, 1995; Kauffman, 1995a). At every nested level there are simple rules that determine complex behaviour of the whole complex adaptive system (Stacey et al., 2000; Gell-Mann, 1994).

[1] Sante Fe Institute – the home of Complexity Science in the US

Hofstadter (1976) suggests that when different levels collapse or become entangled *"producing strange loops and strange hierarchies"* individuals experience a sense of paradox. Things held as separable are shown as inseparable. These loops may be vicious or virtuous (complex systems). If time frames are also collapsed, we may not even see that levels have collapsed.

"The study of complex adaptive systems, from cells to societies, is a study of the interplay among processes operating at diverse scales of space, time and organizational complexity" (Levin, 2002: 3). Levin highlights the relationship between microscopic processes and macroscopic patterns, plus the evolutionary forces that shape these patterns.

4.3.2 Novelty and coevolution

Coevolution is better understood by taking a complex systems perspective. Coevolution occurs when the direct or indirect interaction of two or more evolving units produces an evolutionary response in each (Van Valen, 1983). Responding to feedback loops via adaptive co-evolution, each complex adaptive system attains an ecological niche provided by the mutually accommodative co-evolutionary adaptations of other complex adaptive systems. Predator and prey shift and adapt in a continuous process of evolution. It follows that existing complex adaptive systems within the environment and population may constrain the evolution of others.

Thus complex adaptive systems coevolve with other complex adaptive systems, are nested within bi-directional hierarchies and experience feedback. But the most fundamental property of complex adaptive systems is self-organization. Self-organization refers to the capability to self-reference in the creation of structure. Through the process of social construction, organizations are self-reproductive; they have the capacity to create copies of themselves through augmentation or translation wherein information about the species or class or organization is reproduced (Hofstadter, 1976). An autopoietic system is one that continuously reproduces its internal structure without reference to outside sources in the interests of maintaining its essential identity.

Autopoiesis Theory is derived from neurobiological research into the definition of living systems (Maturana and Varela, 1980). The autopoietic system responds to environmental influences with structural changes which in turn alter its future behaviour. It is a structurally coupled learning system (Capra, 1996) and as it reaches out beyond the boundaries of its own existence, it exhibits self-transcendence, becoming creative. Evolution is the result of self-transcendence at all levels (Jantsch, 1983) and meta-evolution, the evolution of evolutionary processes, a fundamental step in complex adaptive system development.

The notion of self-reference in emergence is evident in many complex adaptive systems. The structure of a cauliflower illustrates fractals, scalability, scale-free theory, and power laws (Andriani and McKelvey, 2007). The cauliflower is composed of branches that have smaller branches that have even smaller branches and so on. The branches look the same and behave the same at each level; this is scalability; their design is fractal. Their adaptive functioning is the same at each level; it is scale-free. Their rank-size distribution will approximate a straight line; a plot indicating a power law effect. Power laws are seen in many complex adaptive systems.

In a dynamic, self-organizing world with co-evolving systems and sub-systems, change and innovation become key features of organization life hence the application of Complexity Science in organizational transformation is relevant (MacIntosh and MacLean, 1999). Via coevolution, mutually interdependent species occupy reciprocal niches in the ecosystem (Kauffman, 1995a).

4.3.3 Adaptation and feedback

Adaptive evolution of a complex adaptive system occurs as its states are modified in ways to enhance its chances for success (Capra, 1996; Kauffman, 1995a). Such adaptive evolution in the classical Darwinian mould is thought to stem from random mutations which are then subject to natural selection (Holland, 1995; Coveney and Highfield, 1995; Hammerstein, 2001). This has been challenged by complex systems thinking. The emergence of new properties occurs as a result of agents interacting, using simple rules, to generate order “for free” (Kauffman, 1995a) via a process of self-organization and autocatalysis or autopoiesis. This conceptualization stresses the holistic view that the whole is greater than the sum of the parts, in which order emerges from the complex interactions within the network of systemic relationships. In a complex world order emerges (Hayek, 1944). Kauffman states that self-organization is the root of order. That emergent order arises naturally and spontaneously within a complex adaptive system by means of its self-organization. "*Whatever their nature, these agents (molecules or neurons or species or consumers or corporations) were constantly organizing and reorganizing themselves into larger structures through the clash of mutual accommodation and mutual rivalry. Thus, molecules would form cells, neurons would form brains, species would form ecosystems, consumers and corporations would form economies, and so on. At each level, new emergent structures would form and engage in new emergent behaviours. Complexity, in other words, was really a science of emergence*" (Waldrop, 1992: 88).

Evolution occurs when there is emergence at the next level of hierarchy. Prior to evolution, the contextual environmental is immature, so when something novel and stable appears, it is snapped up! When evolution occurs, it reflects the culmination of what has been so far. It includes it all and within its new structure, has generated something new (Jantsch, 1983). Capra (1996) considered negative feedback as a self-regulatory mechanism and the key to homeostasis, acting as a self-regulatory mechanism, but runaway effects arise from positive feedback via self-reinforcement or vicious cycles. The effects of feedback in non-linear dynamical systems cause self reinforcing patterns or structures Arthur et al (1987) with positive feedback leading to increasing returns and negative feedback to diminishing returns. Arthur et al define structure as a long-run pattern or limiting behaviour in eventual shares or proportions that emerges from dynamic processes.

As the dynamics of complex adaptive systems are better understood, it is known that multiple equilibria exist and that the static economic models of equilibria apply in a limited way to firms. Arthur (1990) explains that feedback is the cause of multiple equilibria. "*In many parts of the economy stabilizing forces appear not to operate. Instead, positive feedback magnifies the effect of small economic shifts. Diminishing returns imply a single equilibrium point for the economy, but positive feedback—increasing returns—make for multiple equilibrium points. There is no guarantee that* *the particular economic outcome selected from among the many alternatives will be the "best" one. Furthermore, once chance economic forces select a particular path, it may become locked in regardless of the advantages of other paths. If one product or nation in a competitive marketplace gets ahead by "chance" it tends to stay ahead and even increase its lead. Predictable, shared markets are no longer guaranteed”* (Arthur, 1994: 1).

The dynamics of complex adaptive systems are such that the interactions among parts can be material/energetic or informational and may be described by non-linearity, so that small causes are associated with disproportionately large effects in the overall system. Thus, complex adaptive systems display sensitivity to initial conditions, sometimes referred to as the ‘butterfly effect’ after meteorologist Lorenz’s (1963) claim that the flap of a butterfly’s wings in one region of the world could affect weather patterns in others. Significantly, history matters in complex systems: their evolution over time is one of path dependence and irreversibility. The past co-produces present and future system states; change in a complex system follows what Eddington (1930) called the ‘arrow of time’ (Prigogine and Stengers, 1997).

4.3.4 Emergence and macro order

Various types of development may occur in a complex adaptive system. Hierarchic development involves moving to a higher level where there are greater degrees of structuralisation, differentiation-integration and functional capacity among variables (Taylor, 1976); it is transformative and morphogenesis occurs. Developmental movement is of a hierarchic nature where each successive level includes, comprehends or assumes basic characteristics of preceding levels, but also adds its own emergent qualities not found in those levels. Emergence through lower levels is possible; distortions at lower levels are only partially passed on and emergence at higher levels can overcome these distortions. When growth is non-hierarchic it is horizontal and known as translation and corresponds to morphostatis. Initially, higher levels are fused with lower levels; they are entangled with strange loops (1983; 1975).

When oscillations in the ecosystem can no longer be controlled by first order negative feedback, the resulting exponential amplification of deviations can only be controlled by second order negative feedback. When this occurs, a bifurcation point is reached (Prigogine and Stengers, 1984) and the system can transform to a higher level or destroy the system. Emergence depends on a *"certain kind of balance between the forces of order and the forces of disorder – the point of phase transition* (or the edge of chaos (Langton, 1990)) *where there is true complexity"* (Waldrop, 1992: 234). Complex adaptive systems tend to occupy Wolfram's Class IV region – an "elusive mixture of yin and yang", a critical regime between order and deterministic chaos, self-organization (yang) and apparent mayhem (yin).

Many theories attempting to explain order have been explored and are summarized in Table 4-5. The work of Belgian physicist and Nobel-prize winner for chemistry, Ilya Prigogine in the field of non-equilibrium thermo-dynamics, sought to explain the existence and development of order in the world rather than its on-going deterioration and rundown of systems implied by the second law of thermodynamics (Prigogine and Stengers, 1984). There exists a tension between higher and lower energy (and associated states of order) which creates an energy differential that initiates agent self-organization and resultant order creation.

Holland conceptualized emergent structures growing from a deeper substrate that is constantly being adjusted and readjusted by input from the environment (Waldrop, 1992). This phenomenon depends on a combined process of exploration and exploitation, wherein agents produce variations in solutions (exploration) that survive to the extent that they obtain rewards from the environment (exploitation). The *"population of rules would change and evolve over time constantly exploring new regions of the space of possibilities"* (Waldrop, 1992: 189). The same principle of incremental learning is expressed by Jantsch (1983) as self-transcendence.

Evidence and Source	Description
The logistic difference equation of the form $X_{t+1} = r\, X_t(1-X_t)$ Robert May (Li and Yorke, 1975)	Robert May varied r and observed that when r is low, the population becomes extinct; as r rises, so does the equilibrium level of the population; as r rises further, the equilibrium splits in two (a bifurcation) and begins to alternate between two different levels. As r rises further still, the bifurcations occur more frequently until the system becomes chaotic and visits infinitely many different values. May recognised that simple deterministic models could produce seemingly random behaviour.
‘Pink noise’ and ‘white noise’ (Dooley and Van de Ven, Andrew H., 1999)	In their typology, for application in organisation studies, ‘pink noise’ refers to constrained or deterministic chaos and ‘white noise’ refers to systems characterised by complete randomness. Statistical tests can distinguish between the observed dynamics and aid researchers in developing appropriate causal theories.
Phase space and Attractor Basins (Gleick, 1988)	A phase space, that is a spatial representation of a dynamic system characterised by variables plotted on axes as they change over time, may represent 3 discrete types of attractor basin: a fixed point, a limit cycle, or a random walk. The fixed point represents one stable position. The limit cycle is a sequence of positions that repeats itself. The third is the strange attractor where the system fails to settle without repetition. Using simple difference equations, strange attractors have been produced such that given any number of points, it is impossible to guess where the next will appear except that it will be somewhere on the attractor – an orderly disorder or a pattern in chaos.
Requisite Variety (Ashby, 1962)	Self-organized order exists between two entities only if the relation is conditioned by a third entity; that is, order is a function of context (the third entity). Ashby extends this to state that environmental constraints are necessary aspects for order creation, and that by his ‘Law of Requisite Variety’ that for an entity to be “efficaciously adaptive”, the variety of internal order must match the variety of environmental constraints, which in turn must not be chaotic.
I & II → III → “IV” Langton in Waldorp (1992)	Langton explored Wolfram’s division of cellular automata into four classes: Class I – a point attractor leading to a fixed outcome, Class II – a periodic attractor with an oscillating pattern; Class III – strange attractors with a chaotic pattern of unpredictability and Class IV – an unnamed class in which coherent structures propagated, grew, split apart and recombined in complex ways. By varying a parameter Lambda between 0 and 0.50, the system moves from Class I through Class II to Class III. When Lambda equals 0.273, Class IV appears. Class IV became known as the “edge of chaos”.
Dissipative Structures as cause of coarse-graining (McKelvey, 2004b)	Being far from equilibrium means that these complex adaptive systems are subject to high degrees of non-linearity or chaos making predictions impossible even though they show overall patterns of order (Capra, 1996). Prigogine and Stengers (1997) state that the tension between higher and lower energy (and associated states of order) creates an energy differential that initiates agent self-organization and resultant order creation.

Evidence and Source	Description
Critical Values in energy differentials (Lorenz, 1963)	McKelvey (2004b) uses description of the critical values in energy differentials that divide a natural system (velocity of air flow) into three kinds. Below R_{C1} exists stability/determinism, between R_{C1} and R_{C2}, exists bulk movement in a circulatory pattern and above R_C2, exists aperiodic behaviour and strange attractors of deterministic chaos. McKelvey (2004b) defines the 0th law of thermodynamics such that an energy or tension differential R such that is located between R_{C1} and R_{C2} produces new order via agents self-organisation.
Hamiltonian $H = H_c + H_e + H_1$ (Omnès, 1999)	Omnès associates irreversibility, dissipation and decoherence, concluding that only from the dissipation of energy can probability (coarse grained structure) emerge from entanglement and that the energy comes directly from environmental context. H_c relates to internal variables, H_e to environmental variables and H_1 a coupling of the two systems. His total Hamiltonian connects the process of decoherence with the dissipation of tension.

Table 4-5 Theories of complex system emergence

Kogut (2000b) claims that the structure of a network arises from the inherent characteristics of technologies, social norms and institutional factors, based on underlying rules. So structure is not determined only by exogenous factors but is expressed in rules that guide behaviours of interacting entities.

Chaos theory helps to explain how evolution occurs (Kauffman, 1991). When a system is pushed away from equilibrium, for example when an invention is invading, it encounters a 'fork in the road' or bifurcation point. It is at these points that the system can self-organize through unpredictable leaps into different states. If the old dominant organizational form or attractor basin can dissipate the energy and instability then potential changes get dissolved and the system reverts to a variation of its former state. If the new set of influences takes advantage, the energies go into a new configuration. Bifurcation points and attractors always exist as latent potentials within any complex non-linear system and they signal the potentials for self-organization and the evolution of new form. The trick is in identifying an apparently insignificant incremental change that results in large effects.

Bifurcations are changes in which a system makes a transition from steady state to periodic or from periodic to chaotic or back again. Period-doubling bifurcations occur when the periodicity of a system doubles as the value of a variable increase. *"Sequences of period-doubling bifurcations ending in chaos are ubiquitous features of dynamical systems"* (Lorenz, 1995: 70). Dynamic systems demonstrate order and disorder, regularity and irregularity, coherence and turbulence, occurring together, via a system *"locally unpredictable, globally stable"* (Gleick, 1988: 48). The world of macro structure is 'coarse-grained' and arises from the fine-grained structure due to decoherence – the destruction of entanglement (Gell-Mann, 1994). Structural changes over time occur as the result of the change in synergetic bundles that constitute the system. As instabilities occur between the system and the environment, new systems arise with new synergetic structure. The new system will retain some properties of existing systems, but it will also have new properties, making the new system qualitatively different from the previous generation. The new system must have internal coherence for it to be persistent (Allen and Varga, 2008). See Figure 4-2.

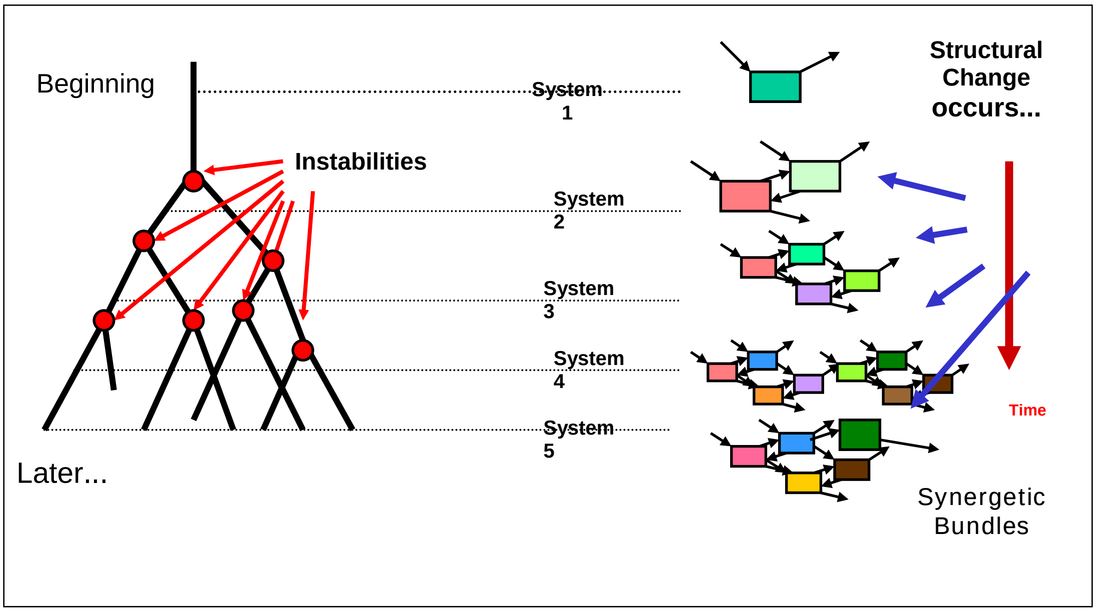


Figure 4-2 Why evolutionary systems are not mechanical (Allen & Varga, 2008)

New macro order arises as a result of tension in the dynamic processes of the self-organizing agents in the system. McKelvey (2004b: 66) concludes that *"Order is now seen to be due to the interactions of autonomous, heterogeneous agents energized by contextually imposed tensions induced by energy differentials"*. Many further examinations of order creation and regions on the 'edge of chaos' have been examined by notable authors. A summary is provided in Table 4-5. The phenomena of emergence occurs, it is observable and qualitatively difference from earlier structure.

On a more philosophical note, Complexity Science addresses complexity as both an ontological question and an epistemological question (Moldoveanu, 2004). Complexity may be seen as an objective system property that correlates with a system's structural intricacy or a subjective system process that correlates with the validity and accuracy of prediction. Boisot and Child (1999) make the same distinction for human systems. The ontological perspective is relational complexity and the epistemological question is cognitive complexity. It does not hold that structural complexity leads to predictive complexity nor vice versa. Structurally simple systems can behave in unpredictable ways and structurally intricate systems can behave predictably.

4.3.5 CAS and the firm

The case for applying a complex adaptive systems perspective to the coevolution of firms is well established (see (Garnsey and McGlade, 2006; McKelvey, 1999a)). In complex systems terms, the environment is merely another layer in a nested system. Every system takes all other systems as its environment. Systems co-evolve as they "complexly adapt" to their environment and which coevolves with the systems that constitute the environment. The environment or landscape that each system faces is changed as a result of changes in the systems that constitute the landscape (Kauffman, 1993). Byrne (1998) argues that complexity science is a way of understanding what things are like, how they work, and how they might be made to work.

Complexity science concerns order creation in the macro environment (McKelvey, 2001). One example is in the use of finding patterns. Maguire (1999) shows how findings in early investigations (Kauffman, 2000) can be connected to exploration in the Configuration school of management (Miller, 1986; Mintzberg, 1990) demonstrating that complexity science provides a theoretical basis for empirical findings, in particular, archetypal patterns of strategy, structure and environment. Another example is the mechanism for change.

Brown and Eisenhardt (1997; 1998) use complexity science to explain how firms engage in continuous innovation and change. From 6 case studies, three properties of firms enjoying success with multiple product innovation and change, are identified: first, semi-structure (that is limited structure with extensive interaction balancing order and disorder), second, links in time (such as experimental products, strategic alliances, predictive reports thus balancing planning and reactive positioning), third, sequenced steps that choreograph transitions from old to new projects.

Complex systems theory offers the notion of 'near decomposability' (Simon, 2002). This technique applied to organizational design will increase the overall fitness of the firm and its capability to mutate. He adds that there must be limits to the independence of components to ensure overall compatibility with the organizational design.

In consideration of the role of managerial intentionality, Volberda and Lewin (2003) identify four co-evolutionary generative mechanisms: Naïve Selection, Managed Selection, Hierarchical Renewal and Holistic Renewal. The Managed Selection engine provides the basis for coevolving self-renewing firms under the control of management. Chandler Jr. (1990) identifies the need for three strategic elements necessary for the success of the firm based on managerial action. First, is investment in production facilities, thereby translating technical know-how into production capability. Second, is investment in marketing, distribution and purchasing networks. Third, is the organization of managers with the ability to operate the firm efficiently.

Evolution of organizational forms must take account of the population of firms. Lewin et al (1999) propose an alternative to organization-environment theories and link firm-level exploration and exploitation adaptations to changes in the population of organizations. The concept of dissipative structures can be used to explain the process of relatively rapid organizational transition from one archetype to another and provide a limited intervention for managers to influence self-organizing processes and archetypal features (MacIntosh and MacLean, 1999).

The garbage-can model (Cohen et al., 1972) shows that problems require attention and solutions have a life of their own, carried by organizational members who look for decision opportunities and come and go as decision participants. This stands in contrast to rational and bounded rational models of decision-making.

Maguire et al (2006: 176) provide a list of reasons for incorporating complexity science into organizational studies.

- *"Limited success of traditional science, as evidenced by poor analytical and statistical results, and inapplicability of findings to managerial action;*
- *Recognition of the iterative or recursive nature of social phenomena, rarity of linear relations and equilibria, pervasiveness of dynamical (non-linear) phenomena, changes to organizational environments that favour adaptability and increasing rates of change in organizations;*
- *Increased appreciation of dynamical formal models and the advantages of agent-based computational simulations and experiments;*
- *Focus on scientific realist methods and explanation instead of (only) traditional logical positivist reductionism and instrumental predictive measures;*
- *Emerging shift from force-based science rooted in physics and with assumptions of independence of units of analysis to bottom-up agent-based or rule-based science in which attention focuses on changes to the interdependent agents or to the rules governing their behaviour; and*
- *Growing appreciation of the need for qualitative, process and holistic types of research along with a re-awakening of the systems-theory precursors to complexity science."*

There are limitations of complexity science methods, mainly in ascertaining appropriate variables and in definitional and measurement respects (Maguire et al., 2006).

4.3.6 CAS and supply networks

A supply network is the connection of firms which as a whole constitutes the end-to-end inception, design, manufacture, production, and delivery of a product. The supply network embraces the firms involved in the interactions and actions. Different supply networks exist for different products and so competition exists. Indeed competition is no longer between firms but between competing networks (Christopher, 2005) of interacting firms involved in economic exchange, embedded in a particular structure (Powell, 1990). Firms that are formally networked, or connected firms that maintain ties, can outperform rivals (Murmann, 2003).

In a supply network, the Orchestrator or Prime or whichever is the most powerful member firm, will usually select their first tier suppliers for a new product. Whilst the Prime might influence the choice of suppliers to the first tier suppliers, the first tier will often select their own suppliers and so on until finally raw materials suppliers are selected. The overall supply network is self-organised in that control is disseminated across many firms in the supply network. The structure is dynamic in that it accommodates the flow of goods, information and services, and the structure evolves over time as strategies change and lead to radical structural change or as suppliers come and go through a process of selection. The supply network may exhibit archetypal behaviour (Choi et al., 2001). If the supply network's archetype is a heterarchical network, then firms belong to the supply network for the interests of the firm itself. The firm may belong to many supply networks and will need to negotiate the demands of each.

The current study is an examination of the coevolution of the firm and a supply network and so it is relevant also to consider the network of connections that constitute supply chains and their effects upon the firm and vice versa. This phenomenon of connectedness is explored by researchers taking various perspectives depending on their home discipline; for example, organization science researchers look at types of alliance, operations researchers look at flows and logistics, economists look at efficiencies of partnering; technologists look at electronic information integration and so on. The network perspective overcomes this narrow view by looking at the properties of the entire network however the myriad of definitions of networks as inter-organizational relationships has contributed to a vast field of diverse literature (Nohria, 1992; Quayle, 2003; Oliver and Ebers, 1998).

Surana et al (2005) state that one of the major challenges in supply chain management is the deployment of coordination strategies leading to adaptive, flexible and coherent collective behaviour in supply chains. They indicate that treating supply chains as complex adaptive systems can be exploited to characterise and model supply chain networks. Collaborative strategies are needed for global supply networks (Johansen et al., 2005), but the attributes of close collaboration are not well understood (Goffin et al., 2006).

Collaboration may be driven by cultural preferences. The difference between Western and Chinese firms was examined using Boisot and Child's I-space (Boisot and Child, 1999) framework. Following an institutional analysis of China's modernization, they show how cultural differences for tolerating and coping with complexity affect organizing. Western firms, comfortable with the operation of 'market capitalism' (Chandler Jr, 1990), prefer to reduce complexity by transacting in markets and bureaucracies using familiar standard procedures. Alternatively, firms can absorb complexity by engaging directly with China's 'network capitalism' through partnerships with local firms and the clans of which they are part (Boisot and Child, 1996).

Choi et al (2001) argue that the behaviour of the supply network can be described as a complex adaptive system, changing constantly and organizing itself without any singular entity deliberately managing it and which emerges over time into a coherent form. Agents in the system act in parallel and behave to increase the fitness of the system, the effects of which can be local and/or global in some complex aggregate so that the behaviour of the complex adaptive system is emergent and not predictable. Critical connectivity between agents enables weak ties to operate and the complex interaction of many loosely-coupled variables means that the system behaves in a nonlinear fashion. Dimensionality refers to the degrees of freedom of individual agents to act autonomously; controls reduce dimensionality acting as negative feedback. The environments of complex systems are dynamic and rugged (Kauffman, 1995a). The state of the complex system is a quasi-equilibrium, between order and disorder. Sensitivity to environmental changes pushes the complex system away from quasi-equilibrium; small environmental changes can trigger hypersensitive behaviour in the complex adaptive system.

Giannakis and Croom (2004) summarise existing research streams relating to supply networks. See Figure 4-3. Systems Theory is used as a means of synthesis in this conceptual framework.

A SUPPLY CHAIN PARADIGM: THE THEORETICAL DOMAIN OF THE 3S CONCEPTUAL FRAMEWORK

DECISION DIMENSIONS	RESEARCH STREAMS	INFORMANT THEORIES
Synthesis	Network Analysis	Embeddedness, Governance, Social Networks Theories
	Industrial Organizational Economics	Institutional Theory, Theory of the Firm (Coase Theorem), Transaction Cost Theory, Property Rights, Value Systems
Synergy	Strategic Management	Agency Theory, Resource-Based Theory, Portfolio Models, Value Analysis, Game Theory, Fuzzy Logic, Contingency Theories
	Inter-Organizational Relationships	(Open) Systems Theory, Interaction Model, Resource-Based Theory, Group Dynamics, Chaos Theory
Synchronization	Operations Management, Logistics, Purchasing	Resource-Based Theory, Transformation Model, Inventory Theory
	Systems Engineering	Industrial Dynamics (Forrester Effect, Burbidge Effect)

Figure 4-3 3S Conceptual Framework of Supply Chain Research Streams (Giannakis and Croom, 2004)

This sub-section has focused specifically on supply networks as complex adaptive systems. The theme of the section was to investigate the nature of complex adaptive systems and to demonstrate this perspective as useful and relevant to the study of socio-economic systems and in particular the relationship between firms and supply networks. The next section sets out the research philosophy and metaphysical assumptions of this research.

4.4 Research Philosophy and Metaphysical Assumptions

"Philosophical thinking resolves around the four pillars of metaphysics, logic, epistemology and ethics" (Chia, 2003: 2).

Ontologically, I perceive reality is continuously in flux and transformation, thus I think of reality as dynamic flows rather than discrete entities. Coevolutionary theory (Volberda and Lewin, 2003) is consistent with a dynamical perspective of the world in which repeatable experiments are not possible – "You cannot stand in same river twice" (Heraclitus, 500BC). Greek philosopher Heraclitus was one of the first Western philosophers to address the idea that the universe is in a constant state of flux embodying characteristics of both permanence and change (Morgan, 1997). This views reality as inclusively processual and takes a *becoming* ontology, in contrast to the dominant Western neo-Parmenidean ontology of *being*. By taking a processual perspective, that of evolution, rather than that of structures and concrete entities, my ontological perspective is that of change. Entities and structures that are uncovered by theory exist in a constant state of flux. New order is created within a continuum and product life-cycles can be accommodated. Biological and abiological forms do not have a single potential future, there is no pre-ordered reality.

Epistemologically, I take an evolutionary constructivist position. Reality exists only in context of a mental framework (construct) for thinking about it, i.e. there is no Archimedean point (foundation for knowledge) as results of inquiry are always shaped by interaction between inquirer and inquired into (Guba, 1990). This philosophical position accepts multiple perspectives and plurality.

An individual's perspective of reality is constructed and whilst we might strive to find *the* truth, we are limited by our cognition to see the truth. Allen (2001a; 2000) reminds us that all knowledge is a reduction of reality of some kind. Each actor perceives the supply network from a local standpoint and so it is not the same for any two actors. However, the research attempts to find the shared beliefs of actors in the aerospace manufacturing network. "I know what I know" is based on evolutionary epistemology started by Campbell (1969).

Complexity Science addresses complexity as both an ontological question and an epistemological question (Moldoveanu, 2004). Complexity may be seen as an objective system property that correlates with a system's structural intricacy or subjective system process that correlates with the validity and accuracy of prediction. Boisot and Child (1999) make the same distinction for human systems, the ontological perspective is relational complexity and epistemological question is cognitive complexity. It does not hold that structural complexity leads to predictive complexity nor vice versa. Structurally simple systems can behave in unpredictable way and structurally intricate systems can behave predictably. This research treats structure and process discretely.

Constructions are held by humans and many theories could explain facts. Guba (1990) describes 4 paradigms, or basic belief systems: positivist, post-positivist, critical theorist and constructivist. These belief systems guide actions taken in connection with disciplined inquiry. They are human constructions and subject to error. A constructivist view-point is also values-based. This perspective is relevant when examining the preferences of interviewees using repertory grid technique, which is described in more detail in chapter 5. My methodological approach is based in dialectics which aims to compare and contrast individual constructions and to generate one (or a few) constructions on which there is substantial consensus.

4.5 Conceptual Framework

This research study is concerned with the coevolution of the firm and the supply network. The conceptual framework is underpinned by the following assumptions.

- The firm is a complex adaptive system and exists in a population of other firms. Relationships with other firms in common supply networks are collaborative, however, relationships with the same firms in different supply networks may be competitive.

- Both a firm and a supply network is an open dynamic complex adaptive system, composed of many parts related to each other and the environment. Each complex adaptive system has the property of self-organization, such that without any explicit co-ordination between its sub-systems, it exhibits emergent forms at the macro level.

- Complex adaptive systems are influenced by negative self-regulatory feedback and loops of positive feedback causing vicious or virtuous cycles (Holland, 1995). Interactions are non-linear such that small changes cause disproportionately large effects at the observable macro level.

- A complex adaptive system has a history; its evolution is path dependent and irreversible. The current description of the firm and supply network reflects the history of the firm, the 'baggage' that makes it what it is. The past co-produces the present and limits the future states of the system.

- Importantly, a complex adaptive system exhibits self-transcendence, thus it learns and evolves.

- Firms and supply networks exist in a particular space and time. The prevailing context is wholly integrated with the evolutionary maturity of the firm and the supply network.

- Complex adaptive systems operate at a point far from equilibrium and are continuously in a state of flux as energy is imported from the environment and its sub-systems. Its parts may be complex adaptive systems themselves or just entities with simple rules.

- The structure or phenotype of a supply network reflects the internal diversity of the system which is formed from all the objects (such as people, assets, resources) in the system and their interactions.

- The internal diversity of the system creates emergent properties at many layers, for example, quality emerges from a particular set of practices, which are directed to optimise desirable features. But the same emergent property may be produced from a different set of practices, that is, the outcome may be produced in more than one way. The property however will not emerge if all requisite practices are not present. Emergence is the result of integration between the part of the system and the environment.

- Emergent structures are limited by the internal diversity of the complex adaptive system. The internal diversity changes with more or less frequency. Existing structures are the consequence of the irreversibility (Prigogine and Stengers, 1997) and path-dependency of the supply network and of the firms, past and present, within the supply network.

- Emergent structures appear when the system bifurcates. The bifurcation point appears to be reached when there is sufficient change to force it away from its current structural attractor. Critical values demarcate phase transitions that cause the system to change its form but these are unlikely to be observed by the agents in the system.

- Emergent properties of the system arise as a consequence of integration between some or all of the objects of the system. Emergence occurs at different layers in the supply network, enabling and constraining the potential for new emergent properties at the next layer (Fuller and Warren, 2006). An example is dyadic relationships contribute to overall supply network relationships. The emergent properties of the firm thus bundle into the integration of the firm in the supply network, creating a new complex adaptive system at the next level.

- Archetypal behaviour may be predictable if the dependent variables are known and performance may be somewhat predictable if the archetype is known. So there is entangled self-organization, or quasi-natural order (McKelvey, 1997) which also takes account of management direction or there is circular order (Romme, 1999).

- Adaptations act in a non-linear way and so the firm's adaptations may improve or contract the performance of the firm or the supply network. The firm attempts to improve its own performance but cannot be sure of the effects of its adaptations. Finding the optimum structure will vary with different environments as the environment is also a complex adaptive system.

Having made these assumptions, the conceptual framework for the coevolution of the firm and the supply network, is a description of four parsimonious aspects of inter-firm characteristics**: structure, integration, dynamics and coevolutionary effects**.

The structure of the supply network is expected to be rooted in characteristics such as ownership or independence, tight coupling or loose coupling, long-term or short-term perspective. This supply network structure will be a particular supply network form and may exhibit archetypal properties.

The integration aspect defines the protocols and methods used for the interaction: language, electronic protocols (via telecommunications networks), and such like. Integration methods attempt to preserve the integrity of interactions.

Dynamics captures the constant state of flux of the complex systems and examines the nature of the exchange. Characteristics may include frequency, magnitude or importance, types of flow (resources, information, expertise, etc.).

The final aspect describes the coevolutionary effects of the actual flows and feedbacks from the exchanges. For example, raw materials flow, and feedback could be quality of materials, delivery precision etc. It is precisely this coevolution in the supply network which allows the supply network to learn, evolve and find ways to improve through self-organization into a more highly performing structure and dynamic within more versatile integration.

Firms belong to a supply network for purposes of socio-economic performance. These are the corollaries of this thesis:

1. Structure is both outcome and enabler of relational activity; the more complex the structure, the more opportunities there are for different integration methods, i.e. coevolution is enabled
2. Relational activity is dynamical; requisite activity creates endurance in structure and conversely inactivity can fragment structure
3. Interaction methods enable the relational activity to subsist

The methodology selected to examine their 'truth' is described in chapter 5.

4.6 Summary

This section has presented the theoretical, metaphysical and conceptual framework that will be adopted in this thesis. A synthesis of evolutionary theory, coevolutionary theory and complex systems theory was presented and so delivered one of the outcomes of the research. The metaphysical position is described as interpretivist, dynamical and evolutionary, answering research question Q2a: "*What theoretical and metaphysical basis will meet the needs of the study?*" The conceptual framework is described and proposes four aspects: structure, integration, dynamics and coevolutionary effects.

The next section sets out the research design and operationalization. This will be used as a framework for the data collection and analysis.

5 RESEARCH DESIGN AND OPERATIONALIZATION

"No empirical study offers certainty that its findings are valid for other populations. Although field studies and surveys may control for some factors and thereby better define a specific population over which results might be statistically generalised, external validity (the applicability of findings beyond the group) is still an issue for them."

(McCutcheon and Meredith, 1993: 246)

5.1 Overview of Research Strategy

The main challenge of applying complexity science methods is in ascertaining appropriate variables and in definitional and measurement respects (Maguire et al., 2006; Pathak et al., 2007). Three issues are identified which need to be addressed in order to determine a suitable research strategy; first is understanding the constraints created by the reality of the firm and the supply network, second is limits to language as a complex adaptive system, and third the limits to knowledge and cognition of anyone individual, either within or outside the system. These issues are examined next.

A complex adaptive system is in a constant state of flux as evolutionary mechanisms catalyze replication and growth into new structures which themselves offer up emergent properties to the evolutionary mechanisms of the system. So the firm and the supply network are always becoming (Tsoukas and Chia, 2002). The firm and the supply network are ontologically real dissipative structures with a continuous flow of energy (Parellada, 2007), constantly changing/becoming. Epistemologically, it is necessary to take an evolutionary stance in which knowledge is contextualized and grounded. The reality of socio-economic systems takes on different meanings as each person's view of reality is different (Guba, 1990). This means that at best any empirical research will only be able to describe the dissipative structure and the objects in the system which are present at the time of the research. If research is conducted at different times, the systems may have changed. The research strategy has therefore been to collect data of a similar type at the same time. This strengthens the arguments for comparison and classification. The limitation is that any conclusion can be said to be true only at that time because the system will have changed. This assumes that we are able to find the right words to describe the system at the time of the research, which is the second issue identified in operationalizing research into complex adaptive systems. Further, as my research is primarily interested in the dynamics between firms in order to say something about interaction and emergent structure of the supply network, the research has been strongly oriented towards identifying characteristics that are verbs, describing processes or activity. Very few researchers have attempted to describe dynamics of firms (Tsoukas and Chia, 2002) and so in this respect there are no agreed variables.

Any variables we might use to describe the complex adaptive system at a particular moment in time are only as good as our vocabulary at that time. In fact we may not have the appropriate words to describe the system until later post-hoc reflection. Second, even if variables could be defined clearly then as language develops the value of the definition diminishes because original meaning is misinterpreted in whatever future understanding there might exist. Modern language is itself a complex adaptive system with new words and meanings emerging all the time (Bickerton, 1990). The research strategy has been to use abstraction where possible, which makes use of core language whose meaning is relatively fixed within the changing vocabulary. For example, in the laddering process of the repertory grid interviews, the process of abstraction allows the current meaning of modern language to be explained in an objective way, identifying and removing subjective meaning.

The third issue with operationalizing empirical research of complex adaptive systems is a consequence of the limits to knowledge of any single individual (Luhmann, 1998). No one person can describe the extant reality of a firm or supply network. Each person's perspective of the supply network is unique (Mouritsen et al., 2003) so even if information if fully and accurately shared; and even if a complete and correct set of variables is selected , it may be interpreted differently by different individuals. The research strategy selected to address this is the use of triangulation within the firm by using the same data collection method upon different individuals. In addition the data collected in the same firm by the use of different methods are also compared as part of the case study process. The use of different methods incorporates the inclusion of qualitative and quantitative types of data.

The essential requirement to situate the research within a body of literature is developed in chapters 3 and 4. The outcome of the review is a long list of potential inter-firm characteristics. It is the empirical research, and particularly the open-ended interviews, which update this long list and refine them into a short list of variables, which are reasonably enduring and can be used to provide meaningful results in the survey to describe the state of firm and supply network coevolution at the time of the data collection (2007/08).

In order to embrace this breadth of research, this thesis employs a mixed methods research strategy (Brannen, 2005) also known as multi-strategy research (Bryman, 2004). The research strategy adopts a research design covering three stages, which use a mix of quantitative and qualitative data types and different methods of data collection and analysis, which are completed in an orderly sequence.

The particular relevance of a mixed methods research strategy is primarily the multi-faceted nature of the research subject which was investigated over a period of 4 years. The benefits of such a strategy Brannen (2005: 5) are

1. to deflect attention from theoretical work specific to particular disciplines, and encourage thinking ‘outside the box’
2. a fit with ‘practical enquiry’ which is relevant to policy-making and practice
3. accords with the delivery of dissemination
4. an opportunity for skills enhancement
5. life long learning and the broadening of the researcher’s methodological repertoire

On point 1, theories of firms and networks exist in many disciplines including transaction cost economics (Jarillo, 1993; Williamson, 1975; Kogut, 2000a), Resource Dependence (Barney, 1991; Pfeffer and Salancik, 1978; Penrose, 1959), strategic choice (Cohen et al., 1972), stakeholder theory (Freeman, 1984) but rarely from a complex systems view (Choi et al., 2001; Surana et al., 2005; Pathak et al., 2007).

On point 2, management research needs to be closer to practice for it to be relevant. The ESRC grant acknowledged at the start of this thesis has been helpful to closing this gap. However, this thesis is not Mode 2 research (Keleman and Bansal, 2002) as the research question was not defined with practitioners. Although practitioners are becoming familiar with complexity science terms, in particular terms such as, non-linearity, feedback, chaos, the foundation of knowledge in this area is not embedded and so its relevance is not yet well understood.

The last three points stated above as benefits to a research strategy are always desirable in good measure.

The primary objective is to explore coevolutionary dynamics between the firm and the supply network. An outcome of coevolutionary dynamics is the dissipative structure of the supply network. One of the methods which will aid in the discovery of patterns in the structure is to locate clusters of similar characteristics based on the assessments of the multi-dimensional characteristics within the supply network. The questionnaire survey instrument is designed to capture respondent beliefs and understanding from two perspectives. First, is the notion that a characteristic in the supply network is adopted in order to achieve one or more performance outcomes or success criteria. Second, is the idea that the interaction between pairs of characteristics may be of at least as much significance as their first order or primary purpose (Axelrod and Hamilton, 1981).

5.2 Research Design

A research design should make clear the unit of analysis, the research methodology and the research methods (Chia, 2003). This section elaborates on these aspects, providing the rationale for the thesis. A summary of the research design is given in Table 5-1.

The first stage is inductive and aimed at discovery. The research stage examines the three largest firms in aerospace manufacturing using data in the public domain. The research logic is for discovery, in the context of innovation, strategy and organization. This research is already published (Varga and Allen, 2006) and cited in peer-reviewed journals (Pathak et al., 2007; Arranz and Fernandez de Arroyabe, Juan C., 2008). Other published works, conference papers and submitted papers are given in Appendix A.

Dimension of Research Design	**Stage 1 – public domain study**	**Stage 2 – interview**	**Stage 3 – questionnaire survey**
Logic of enquiry	Discovery	Verification and elucidation	Analysis and theory building
Unit of Analysis	Firm	Supply Network	Inter-firm characteristics
Data types	Text (from company reports)	Text (from open-ended and semi-structured interviews); Text from repertory grid technique laddering process; Integers (interval data) from repertory grid technique	Integers (interval data) from 1. Performance table 2. Pair-wise Matrix
Data collection	Extracted from published company annual reports on company web sites	Face-to-face open-ended interviews; Telephone interviews (only for semi-structured interviews); Face-to-face Repertory Grid interviews	Spreadsheet via email
Data content validity	Published reports ratified by directors and auditors	Multiple responses in same firm; Collaborative responses	Multiple responses in same firm; Collaborative responses
Data analysis method	Coding using N-Vivo	Coding using N-Vivo (for text); Factor Analysis (for numbers)	Cluster Analysis using SPSS; case comparison
Inter-rater reliability	Declared coding framework	Crawdad Text Analysis System for text	Declared coding framework
Reasoning	Inductive	Inductive	Deductive
Method	Historical Case Study	Field-based Case Study	Survey

Table 5-1 Research Design

The second stage obtains empirical evidence from individuals with respect to their supply networks. Interviews were held at 8 multi-national firms in commercial aerospace manufacturing based at different tiers of the supply network. Multiple informants were used in all firms. The purpose of the second stage was four fold: 1. to confirm the inter-firm characteristics found in the literature; 2. to identify new characteristics not previously mentioned in the literature; 3. to create content-rich case studies and 4. to compare cases and find explanations for differences. "*For while systematic data create the foundation for our theories, it is the anecdotal data that enable us to do the building. Theory building seems to require rich description, the richness that comes from anecdote. We uncover all kinds of relationships in our hard data, but it is only through the use of this soft data that we are able to explain them*" (Mintzberg, 1979: 587). The importance of rich qualitative data has driven the creation of the case studies and helped enormously to understand the nature of commercial aerospace manufacturing.

The third stage is a survey intended to identify patterns of characteristics from which supply network dynamics and related supply network forms can be deduced.

The logic of enquiry (see first dimension of Research Design in Table 5-1) drives a research study (Brannen, 2005). As with many theses, this research has multiple stages each of which is driven by different logic. The logic of enquiry is based in the sequence of stages, one stage depending upon the previous stage's results thus the ordering of the stages has explicit relevance. The examination of the primes at the first stage influenced the formulation of semi-structured questions for the interviews at the second stage. The interviews in the second stage influenced the final set of inter-firm characteristics in the survey demonstrating the relevance of field-based research and its grounded nature for more readily defining constructs for theory testing (Eisenhardt, 1989).

Eisenhardt (1989) also suggests that qualitative evidence is 'words' and quantitative evidence 'numbers' and claims that this combination of data types can be highly synergistic. The relative value of qualitative and quantitative enquiry has been debated for some time (Jick, 1979; Patton, 1990). Qualitative research attempts to locate phenomena in a context-based setting which is not arrived at by statistical means (Strauss and Corbin, 1990). Qualitative data are useful for supplementing, validating or explaining quantitative data (Miles and Huberman, 1994). Quantitative research uses experimental methods and quantitative measures to examine generalizations. Quantitative data can be inflexible and artificial, and not very effective in understanding processes or meanings attached to them (Easterby-Smith et al., 1994). This study draws insights from a cross-section of methods which combine both qualitative and quantitative methods. A mixed-method approach prevents the research becoming method-bound and counter-balances the strengths and weaknesses of each method (Easterby-Smith et al., 1994).

The mixed methods research strategy which incorporates not only multiple methods to collect and analyse data about the cases, but also uses data of different types, strengthens the internal validity or credibility (Miles and Huberman, 1994) of the results.

The data collected from the different methods is not something that can be 'added together'. In early practice of social science, triangulation was used to show how results obtained from different methods validate or corroborate each other (Denzin and Lincoln, 1994). If we no longer assume that there is one reality and accept pluralism then each account serves a different purpose (Hammersley, 2008). But there are ways of combining research results other than for the purposes for corroboration (Brannen, 2005):

1. Elaboration or expansion; data analysis of one method adds to the understanding being gained by another
2. Initiation: new hypotheses or research questions from one method triggers research using a different type
3. Complementarity: qualitative and quantitative results are treated differently but can be juxtaposed for greater overall insight
4. Contradiction: discount one method over another where results contradict each other, favouring validity or reliability

The process of validation seeks to limit the risk that the research findings are wrong. The methods to achieve validation are dependent on the nature of the research.

Clearly, with an exploratory study taking a novel perspective, comparison against results from traditional perspectives will not aid in the validation process. Thus the findings must be judged in respect of their relevance to practitioners. Similarly, reliability aims to ensure a consistency of results and stems from positivist science. For Interpretivists, the auditability and dependability of research can be assessed (Miles and Huberman, 1994). The process of triangulation is used in this research as advocated by Yin (1994) and in particular the exploration of outliers or unusual results.

The next three sections examine in detail the methodologies for each of the three stages. A summary is provided in Appendix B of the methods used in the thesis for N-Vivo (text classification), Cladistics (phyletic classification) and Repertory Grid (structured data analysis), indicating their strengths, their purpose, issues with the method, validity and limitations.

5.3 Research Methodology for Stage 1 and Stage 2

This section describes the processes and decisions involved in stages 1 and 2. They are described together as both stages involve the use of case studies. They differ in that stage 1 is an historical study whereas stage 2 is empirical. The section is formed of six sub-sections. The first two sub-sections take an overview of the research methodology of each stage respectively. The third sub-section describes the case study approach. The next two sub-sections detail the process of data collection and data analysis of open-ended and semi-structured interviews for stage 2. The sixth and last sub-section describes the use of the structured repertory grid interviews.

5.3.1 Stage 1 research methodology

A grounded, qualitative, inductive approach was taken in examining the public-domain data related to the three firms in this case study. The three largest firms in aerospace manufacturing were selected because of their size and so influence and leadership status in the industry.

A breadth in data coverage and data source was the target as the focus on the case study was to identify specific organizational constructs relating to evolution. The use of multiple sources permitted some triangulation. However, all data used were public domain, second order data and so my interpretation of this interpreted data will bias my results.

The primary source of data collection for the purpose of identifying company strategy and the innovations of each of these firms were the Chief Executive Officer (CEO) statements in current published annual reports. These reports were coded sentence by sentence using content analysis to identify constructs that each CEO (or his writer, even though signed by the CEO) had used to describe the evolution of the firm. These constructs were then organized into themes for each CEO report on a within-case basis by clustering constructs that were similar. The specific words and language used in each CEO statement plus frequency and size devoted to the construct, together with the themes, were analyzed in order to arrive at some conclusions as to the relative importance of evolutionary activity of the firm. The emphasis indicated by the CEO of particular evolutionary activity, for example, by stating that this ‘came first’ or ‘was most significant’ was used as a gauge to assess its relative importance to the firm. Each CEO statement was analyzed in this way and triangulated with business reports (via electronic business data sources) regarding these companies. Where anomalies were found between CEO statements and business reports, some scepticism was recorded against the relative importance of the CEO emphasis. In addition, the companies’ web-sites were used to obtain further details of each of the innovations mentioned in the annual reports. Cross-case assessment was carried out as the final stage of analysis to explore the differences.

5.3.2 Stage 2 research methodology

A case study approach was taken. Eighteen open ended interviews were held with key individuals in commercial aerospace primes and first tier suppliers. Individual transcripts extending up to 8,000 words were each recorded. The approach allowed interviewees to express important aspects of the nature and management of supply chains without interviewer prompting. This was essential for two reasons: first, in order not to prejudge the relevance of the characteristics and second, in order to identify the current perceptions of supply networks which may not yet be published. Coding was carried out in Mind Manager, a mind-mapping software tool. A first analysis looked for key words (and synonyms) based on the researchers understanding from the literature review in chapter 3. New categories were created if the literature appeared not to have covered a topic. A second analysis took a two-step approach of within-case and across-case analysis (Eisenhardt, 1989; Yin, 1994). Themes were located within each case and these themes were compared across cases. Care was taken to record the supply network tier at which the interviewee worked to look for similarities and differences across tiers.

Case selection was driven by the need to ensure adequate variety of cases in particular at different tiers of the supply network and different types of firm, intending to incorporate extreme and polar types (Pettigrew, 1990). Variety is more important than the frequency (Ragin, 1987) as notions of sampling are less relevant in case study research. This variety should create adequate possibilities for deviation which should be accounted for in any theory developed from the cases, so replication logic applies, rather than sampling logic (Eisenhardt, 1991).

Three types of interview were used: open-ended, semi-structured and structured (using repertory grid technique). Open-ended interviews are unstructured and free-ranging but within the overall scope of the supply network, with the primary purpose of understanding the meanings interviewees attach to aspects of the supply network without being influenced by the researcher's assumptions (Easterby-Smith et al., 1994). Semi-structured interviews attempted to delve into specific aspects of the supply network (see Appendix E for the interview template).

5.3.3 Case study approach

This section presents the detailed process for the case study work in stages 1 and 2. As a reminder, stage 1 was an historical case study of the three largest firms in aerospace manufacturing, and stage 2 was an empirical case study of a cross-section of 8 firms in aerospace manufacturing. Both case studies present individual case results and then compare the cases. A case study approach has been chosen because this research strategy is well suited to new research areas (Eisenhardt, 1989) or when new perspective are sought or there is little knowledge of the phenomenon (Patton, 1990; Patton, 1987).

A multiple case approach was selected because the unit of analysis, the supply network, straddles firms in many tiers. The adoption of a single case or one firm perspective would provide too narrow a view. Nevertheless, the multiple case approach is not intended to be a macroscopic study and has only limited generalisability (Hamel et al., 1993; Yin, 1984).

Multiple methods are used for each case. Ragin's 'case oriented comparative methods' (1987) and later fuzzy-sets (2000), demonstrates that case-oriented research using multiple methods finds reasons for deviating cases, and so creates a rich dialogue between theory and evidence. The use of multiple methods is typical for theory building (Eisenhardt, 1989).

The quality and rigour of case studies can be tested using Yin's (2003) case study validation approach. This involves establishing 1) construct validity, 2) internal validity, 3) external validity and 4) reliability. Constructs were validated by comparison against the literature review, by cross-case comparison, the use of qualitative and quantitative evidence and by affirmation from respondents to the survey. Yin states that internal validity applies only to explanatory and causal studies, however, an attempt is made to validate the relationships between constructs by using alternate methods to arrive at similar results, by using pattern-matching (Campbell, 1975) applicable to small-N case study research. The study uses this approach in Chapter 6. External validity is tested by establishing the limited domain to which the results apply. Reliability is tested by presenting a transparent coding scheme and referencing public domain data where possible.

Yin (1994) identifies five components of research design, important for case studies. The study's questions (1) are identified in Chapter 1. The propositions (2) and logic linking the propositions (3) were discussed in Chapter 4. The Unit of Analysis (4) is the Supply Network. Finally he notes the need for criteria for interpreting the findings (5). As multiple respondents were used in all firms, this is addressed. The criteria used for validating the case study results in this thesis are set out below:

1. Frequency of term or phrase; or adverb/adjective denoting importance
2. Coherence of terms, i.e. ignore contrasting comments unless explained
3. Similar results are predicted for some firms (literal replication) and contrasting results are predicted for other firms (theoretical replications)
4. Corroboration by at least one other source, to verify authenticity.

5.3.4 Case study data collection

Data was collected from interviewees largely on a face-to-face basis. Only 4 interviews were telephone interviews and these were semi-structured in nature. Most interviews were recorded electronically. All interviews were typed-up into electronic format (MS Word) providing a permanent record of the research.

Additional information was sourced via two streams. The first was information in the public domain, including publications from the firm, and comment and news, via the internet. The second was via documents, usually charts, organ-o-grams and MS PowerPoint slide shows provided by employees of the firms being researched.

All data collected protected the privacy and confidentiality of the individual respondents. This was declared prior to interview and maintained by good records management after the interview. The focus of the research was not to make a critical investigation nor was there intention to expose unethical behaviour or malpractice. Confidential information provided regarding specific suppliers was anonymised in order to protect the commercial confidentiality of these firms.

The firms providing the source data were extremely helpful and I am very grateful for their contributions. Obtaining access to firms was difficult for various reasons. Firstly, firms do not have spare capacity in the schedules of senior directors and vice presidents, who are extremely busy. Secondly, firms are looking for a return on any relationship with academia. Whereas academia recognizes the value of research in peer-reviewed publications, this is not always accessible or relevant to the practice of the firms. Volume output is a further issue. Where some 5,000 words is not unusual for an academic paper, around 300-1500 is desirable for a firm. Lastly, firms are often already in a relationship with an academic institution and therefore do not desire a competing or contrary relationship with another one.

The interview and survey data obtained for this specific research was a direct consequence of three relationships. The first was the grant from the ESRC - RES-000-23-0845 “Modelling the Evolution of the Aerospace Supply Chain” 2005-2008 and the second was Professor Allen’s relationship with the President of an Aerospace Group and the third was the researcher’s relationship to the Procurement Director of a second tier supplier.

These relationships provided access to firms at three tiers of the commercial aerospace manufacturing supply network. In particular, the first two relationships spawned relationships with the suppliers (and competitors) of these firms, extending the range of firms contributing to the research. There was no question of planned theoretical or selective sampling as the researcher accepted the contributions of the firms able to support the research. As Pettigrew (1990: 274) puts it: “*there is an intentional or design component in the process of choosing and gaining access to research sites, but the practicalities of the process are best characterised by the phrase ‘planned opportunism’*”.

5.3.5 Case study content analysis

Content analysis was managed by using ethnographic coding techniques (Strauss and Corbin, 1990). Open coding was applied independently to each interview transcript, coding sentence by sentence. This was a means of analysing text without applying preconceptions for the purpose of discovery and not final closure. Text is labelled and categorized with attention given to words used by the interviewee. A mind map was built up for each transcript facilitating the use of the *constant comparative method* in which existing codes and categories aided decision making for new codes. At the same time, new text would trigger the revision of existing codes and categories, sometimes causing the merger of codes or more often the division of codes into greater granularity thus more specific meaning. Codes were re-sorted into different and sometimes new categories and the categories themselves remained open to reconfiguration until the full text had been processed.

Theoretical saturation was sometimes achieved when the transcript had been about two-thirds processed; that is, no new codes or categories were identified in the latter part of the transcript. Nevertheless, some transcripts raised new phenomena even in the last line. The coded and categorised transcripts of two interviews at a Prime are shown as mind-maps in Appendix C.

Memos, which are theoretical notes, were noted during the open coding process and recorded in the mind-maps with links to the appropriate codes or categories triggering the observation. The core category in the vast majority of interviews was the supplier and in others was the firm. Transcript text related more frequently to the core category than to other categories. Core categories are discussed in more detail in the case results. Axial coding was used as a way to find relationships between codes and categories and are included on the mind maps as lines between codes in different categories. The categories and relationships became saturated and so theoretically complete (Glaser and Strauss, 1967). Corroboration of codes and categories was achieved via independent coding and via the Centering Resonance Analysis (CRA) tool, which uses concordancing to arrive at frequently used words and words used frequently together (Williamson et al., 2004). Appendix D contains two of the CRA results.

Open-ended interviews were the most straightforward to code with the above scheme. Another coder was asked to code two interview transcripts in order to identify significant mismatches or bias in the coding process. The coder’s results agreed at around the 90% level thus inter-rater reliability gives adequate assurance that coding was consistent (Rungtusanatham et al., 2003).

A secondary purpose of these interviews was to verify the on-going relevance of supply network characteristics found in the literature and to reveal any new characteristics which had not been explicitly included. The outcome of this is described at the beginning of Chapter 7.

The semi-structured interviews collected information relating to specific categories, which themselves had been decided by a combination of literature review and the coding of open-ended interviews. Coding of semi-structured interviews therefore sometimes required a little ‘unravelling’ of the orderly semi-structure, to create an improved categorisation. The semi-structured interview templates are contained in Appendix E for reference.

Coding of the structured interviews is relevant to the ‘laddering’ process. This is described in more detail in the following section. The coding released its own hierarchy of categories, although this hierarchy was more circular than linear, as an interviewee could fail to abstract, finding it easier to return to something said earlier in the laddering process.

Once the coding was completed from the different methods of collection, a comparison against literature was completed. The whole process from research design, through data collection, analysis and comparison with literature enables grounded theory to be developed (Pandit, 1996).

5.3.6 Repertory grid technique

This sub-section describes the structured interview methodology used in firms as part of stage 2 of the research design. The sub-section contains an introduction to the Repertory Grid Technique, its design for this thesis, a description of the interview process, and the process of analysis of the interview data.

5.3.6.1 Introduction

Repertory Grid Technique as a research method facilitates insights into highly complex organizational phenomena by identifying value-based constructs from respondents in a structured manner (Fransella et al., 2004). Known as Rep Grid, it was developed for use in psychology by George Kelly (1955) as a way of implementing his theory of personal constructs. “*A person's processes are psychologically channelized by the way in which he anticipates events*” and “*a person anticipates events by construing their replications*” (Kelly, 1955: 46). The technique has been applied successfully in management research within different disciplines (Fransella et al., 2004) and is *"an outstanding example of how the phenomenological emphasis of constructivism can be reconciled with quantitative research"* (Botella, 2007: 4).

It is argued (Kelly, 1955) that the construct systems we create influence our expectations and our perceptions. Construct systems can change. Some constructs are more important than others and not always internally consistent. In addition, the extent to which one person can understand another person's construct system is a measure of personal empathy. The outcome of the Rep Grid interview is in two parts. The first is a list of constructs (and their poles) which has been elicited as part of the structured interview. Associated with this elicitation are the decisions made by the interviewee in arriving at these constructs. The second part is a matrix in which cells are rated. Constructs can also be ranked by the interviewee to indicate relative importance. The Rep Grid technique creates qualitative interview data and matrices of quantitative data conjointly (Goffin, 2002). Results can be examined permitting the identification of variance in constructs, the production of cognitive maps and the identification of principal components (Goffin, 2002).

When the Rep Grid Technique is conducted in a way which accepts the interviewee's first mentioned construct, it is often difficult to compare constructs between interviews as they can be located in disciplinary-based language with specific meanings. In order to make comparison more meaningful, modern everyday vocabulary is required. This is carried out using a process of abstraction called 'laddering' which also identifies causal links between personal constructs and values.

Means-End Theory (Gutman, 1982) is applied by Reynolds and Gutman (1988) in their definition of Laddering as an in-depth interviewing technique which elicits a hierarchy of attributes, instrumental values and desired end-states. The divide between traditional, ideological approaches and the modernist, positivist way (MacIntyre, 1990) are brought closer together in this research design as the value systems of individuals are exposed in the process of extracting personal constructs. Laddering encompasses the process of personal construct identification using triadic sorting (Kelly, 1955) which is a fundamental process of repertory grid technique.

Personal constructs enable individuals to differentiate between objects, e.g. the products produced by different suppliers may be differentiated by their quality. As a consequence of this differentiation, a construct has two parts or two poles. These two poles need not be dichotomous, such as 'high quality' and 'low quality'. The poles may simply differentiate between the objects, such as product quality and process quality. By asking the interviewee for a preference between the poles and why they hold this preference, a hierarchical value map is elicited, ending where possible in the interviewee's terminal values.

Repertory grid technique was selected as a data gathering and analytic method because it readily accesses constructs which are not easy to articulate by interviewees in other interview methods, it identifies interviewee preferences, prevents researcher bias and acts as a form of triangulation for data collected by other methods.

5.3.6.2 Repertory grid design

The design of the Rep Grid interview requires planning. The first is to decide what objects to compare. Stage 2 of the research design focuses on the supply network as the unit of analysis. It was decided to select suppliers as the objects.

The second requirement is to compare as broad a range of objects (suppliers in this case) during the time of the rep grid interview. Suppliers are compared in triads, groups of 3. The scheme of triads will differ depending on the number of suppliers identified by the interviewee. Appendix F states a general purpose scheme of triads (Varga, 2007). The scheme ensures maximal exposure to all objects which has not been the case in other reported studies.

5.3.6.3 Repertory grid interview

The interview process using Repertory Grid follows a structured process. The first step is the identification of objects. As little as 5 and as many as 10 suppliers with which the interviewee was familiar are identified. The supplier names are placed at the head of the columns of a blank repertory grid. A post-card sized card is used, onto which the name of one supplier is written. The second optional step is to request brief details for each supplier. Appendix G shows the information collected for this study which provided ways of comparing suppliers in later analysis.

The third step is to present triads to the interviewee in the order they appear in the triad scheme. The triads are presented by showing the relevant three cards which identify the suppliers in the triad. The interviewee is asked to say what is similar about two of the suppliers which is different from the third. The interviewee is then asked for a preference between the two initial constructs they state and the process of Laddering starts. The interview text at this stage is qualitatively rich and provides evidence of the specific abstractions used by the interviewees which can be used in later analysis. The continued questioning of why a construct is preferred, and then why the reason is preferred and so on, will end in some final construct or answer, which becomes the construct used in the repertory grid matrix. The pole is also agreed with the interviewee at this stage.

Once the laddering process is complete and so the final pair of constructs is known, these are written on a new row of the repertory grid, with the preferred construct on the left and the pole on the far right. If the construct pair duplicates a prior construct on the repertory grid, then it should not be used.

The fourth step is to rate each cell in the repertory grid once all triads have been compared. If a supplier exhibits the characteristics of the preferred construct, the rating is 1; if the supplier is like the pole, the rating is 5. Ratings of 2, 3, and 4 represent a 'best' position along the continuum between the construct poles. There should be no blank cells remaining after this last step.

A final optional step is to rank the preferred constructs. This allows another means of comparison with other repertory grids.

5.3.6.4 Rep grid content analysis

The validity of the completed repertory grid is checked prior to analysis. During the laddering process, the interviewee will have differentiated between triads of suppliers.

Suppliers who are identified as having the attributes of the preferred construct should have a low rating (1 or 2) in the completed grid. In contrast, suppliers who were marked as being like the pole, should have a high rating (4 or 5).

Any columns which are complete duplicates should be removed. These suppliers are construed in exactly the same manner and so do not provide any differentiation for analysis.

Each repertory grid can be analysed in many ways as a single case. The method used was to find the variance in ratings for each construct. Those with the greatest variance differentiate suppliers the most. Principal components are found for each repertory grid. Finally, content analysis was used to analyse the text used during the laddering process.

Cases can then be compared within firm and across all firms by replication (Yin and Heinsohn, 1980).

A further stage is possible by identifying the most frequent constructs, or those with the greatest variance. In order to expose those constructs (or elements) that can explain the most variance (σ^2), the formula for variance in Equation 5-1 can be used to find the average of all the squared deviations from the mean.

$$\sum (x-\mu)^2 \Big/ n$$

Equation 5-1 Variance for Repertory Grid Constructs

This process allows constructs to be ranked and a short list to be created, which can then be rated by several respondents. Although difficulties arise with this, such as lack of shared understanding of the construct meaning, it can be a useful technique for comparing a wide range of respondents. An alternative is to carry out the laddering on the consolidated list of constructs (Baker, 2002). The benefits are a higher degree of standardization across different samples, and addressing limitations with individual respondents who do not really 'know' the objects well enough to differentiate between them. A key disadvantage is the departure from Kelly's emphasis on the personal nature of constructs.

5.3.7 Summary

This section has described the case study methodology for stages 1 and 2 of the Research. It detailed the design, collection and analysis techniques for the case studies.

The next section describes the research methodology for stage 3, which is a questionnaire survey and cluster analysis.

5.4 Research Methodology for Stage 3

The final stage of the research design is a quantitative survey. Questionnaire surveys are commonly used when the items can be clearly defined and commonly understood (de Vaus, 1999). This approach is therefore appropriate by stage 3 of this research design, when the characteristics are known and validated.

Surveys are presented in standardised format in order to collect and generate a structured, systematic data set which can be manipulated using quantitative techniques. In many surveys, a sample of the population is surveyed from which generalizations may be made to the population (Malhotra and Grover, 1998).

Whilst the characteristics for the survey instrument were validated, the survey itself was exploratory rather than explanatory (Kerlinger and Lee, 1999). The results have been used to explore possible relationships between supply network structure, integration methods and dynamics of practice. Some propositions do arise as a result of the survey, so sample representativeness is not an issue (Malhotra and Grover, 1998), nor is response rate (Oke, 2003).

The informant targeted for a response was the Director or Vice-President of Supply Chain within the firm or within the aerospace group.   This was deemed to be individual who would have the widest knowledge and experience within the firm to answer all aspects of the survey which would take under one hour to complete.

The objective of survey analysis is to identify patterns within the quantitative survey data. The method adopted to achieve this objective is cluster analysis. The survey is operationalized in two parts: Table 1 captures the perceived effect of an inter-firm characteristic on the performance of the firm; Table 2 captures the perceived effect of an inter-firm characteristic upon every other inter-firm characteristic used by the firm. Cluster analysis is carried out on completed Table 1 and Table 2 surveys. This thesis extends previous research by providing a third set of results which combine Table I and Table II survey forms, and so takes account of both primary or first order performance effects and second-order effects (from highly positive through neutral through highly negative) based on the interaction of these characteristics. The thesis is that this method provides a more balanced and accurate description of the real performance of the supply network.

Finally, some analyses are provided of the survey data from demographics and the spread of ratings in each part of the survey.

5.4.1.1 Survey risks

Establishing the survey instrument involved identifying the risks and actions needed to avoid potential pit-falls in the creation, operation and analysis of the instrument. The specific risks identified are shown in Table 5-2, together with the action which was taken in this study. The detailed actions are described in more detail through this section and in Chapter 7 which details the findings of the survey implemented in 2008.

5.4.2 Survey design and administration

The purpose of the design was to enable an evaluation of the effects of inter-firm relationships upon supply network performance. There exists a first-order and second-order aspect to all performance.

First order performance measures primary effects of adopted characteristics upon performance. This is relatively straightforward complicated only by the fact that characteristics are adopted for specific or multiple performance outcomes. Five performance outcomes (or success criteria) were identified during literature review (see Chapter 3, Section 5). These were validated during stage 2 of the research design. The 27 characteristics, created initially from literature review and further refined by interviews at Stage 2 of the research design (see Chapter 7, Section 2) were listed in a simple matrix with 5 columns for the 5 performance success criteria. Thus 135 cells (27x5) need to be completed for each Table I. Integer responses were required in the range 0-9. This matrix formed Table I of the survey instrument and an empty matrix can be found in Appendix H.

Risk with Survey Instrument	**Action to mitigate, avoid or transfer**	**References**
The use of the key informant methodology by researchers creates bias	Recognise Common Methods Variance (bias in Key Informants)	(Jick, 1979; Snow and Hambrick, 1980)
	Recognise issues of agreement and reliability when using multiple raters	(Kumar et al., 1993; Boyer and Verma, 2000)
Single-item measures are not sufficient to operationalize inherently complex business concepts; Use of single items preventing internal consistency reliability	Use of multi-item measurement scales to reduce measurement error by providing a more robust construct of complex variables through the averaging of several related items	(Stratman and Roth, 2002)
Corroborative evidence may be biased	Retrospective data and sources of data inaccuracy	(Huber and Power, 1985)
Getting the measures right – scale development Measurement quality – reliability and validity of measurement instruments	Understanding the measurement issues	(2003; 2000)
	Measurement of item and scale reliability and validity; Scale development good practice	(Rosenzweig and Roth, 2004; Hinkin, 1995)
Falling through the gap between theory development, construct production and survey items	Bridging the gap between theory and survey production	(Malhotra and Grover, 1998)
Risk of not obtaining high response rates	Use appropriate techniques to gather information	(Frohlich, 2002)
	Understanding bias in non-responses	(Armstrong and Overton, 1977)

Table 5-2 Survey Risks and Actions

The design of Table I extends previous research in two ways. Table I of the survey employs methods used in Organizational Systematics (McKelvey, 1978) and Cladistics (McCarthy, 1995; McCarthy and Ridgway, 2000) in which organizational forms can be detected based on the characteristics adopted. The extension to existing methods provided by this research is to recognize that characteristics are adopted not just for a single purpose but for a small number of key performance success criteria. There is a trade-off in the adoption of a characteristic in that its adoption has a cost and not always a high return in each key performance success criteria.

The second order effects of adopting these 27 characteristics are the inter-characteristic effects. These were captured in Table II of the survey instrument. The Table II pair-wise matrix requires respondents to evaluate the effect of each supply network characteristic upon every other characteristic. Responses measure the inter-characteristic effects on an interval scale from -5 to +5; they are described as pair-wise effects in the following discussion.

Table II of the survey instrument thus consists of a pair-wise interaction matrix. This matrix formed Table II of the survey instrument and an empty matrix can be found in Appendix I. A matrix in this format, but with different characteristics, was used for automotive manufacturing as part of the ESRC Nexus Project to find bundles of synergetic characteristics (Baldwin et al., 2005). These bundles identified organizational forms within the automotive manufacturing industries, using *only* pair-wise interaction matrix survey results.

The survey instrument for the purposes of this research therefore consists of two tables: Table I for first order performance scores, and Table II for pair-wise, inter-characteristic effects.

Whilst simple in design, administering the survey by interview was likely to be onerous because of the need for the respondent to 'see' the table at the same time. Using the experience of colleagues in Sheffield University's Industrial Manufacturing Unit who had previously administered such surveys, it was decided to email the survey as an electronic spreadsheet, so that recipients could complete the survey via their personal computers and without needing to write anything down. This was possible because the questionnaire design was simple. It achieves the highest quality of responses as the interviewer cannot influence answers and the respondent completes the survey at a time (or over multiple sessions) to suit their own convenience. It is also the cheapest form of data collection as it avoids excessive researcher costs particular when the firms are located across the globe.

The questionnaire survey was addressed to the Director of Supply Chain. This person was asked to coordinate multiple responses for the firm. It was anticipated that this person or their direct reports would be able to interpret accurately the effects of supply network characteristics. The individual is probably the best informed of all potential candidates but could be judged to be remote from day-to-day interactions. This was mediated by responses from multiple respondents in the same firm.

Requests for completion of the questionnaire surveys were distributed to the largest (measured as either turnover or number of employees) aerospace manufacturing firms with SIC code 3530 (aerospace manufacturing found on FAME (electronic database of registered companies) in combination with known firms at Sheffield University. Survey responses were received from all tiers of firms: primes, 1st tier and 2nd tier, from individuals in the ratio 15:35:40 respectively reflecting the smaller number of primes. Implementation problems (de Vaus, 1999) arose, with difficulties in obtaining responses. All responses could be used since only valid responses were supplied. 3 null cells were the maximum incomplete per survey (from a total of 351 cells). The quality of the responses was judged by random sampling of survey responses, to check the spread of ratings (see Chapter 7, Section 6). The questionnaire design was such that the respondent could add further characteristics and/or further performance criteria, although none did so. Most respondents expressed some exhaustion after completing Part II of the survey instrument which was the pair-wise matrix. 27 characteristics appear to be excessive for such as survey. The design of the matrix could be altered to break it into smaller components, alternatively, the use of a real-time electronic means of collection which allows the selection of characteristics practised by the firm, would make implementation easier.

5.4.3 Survey Data Analysis

This sub-section describes the rationale for combining various sub-sets of survey responses for analysis. As there are two discrete Tables in the questionnaire survey, there are three scenarios for data analysis: use of only Table I (first order) data, use of only Table II (pair-wise) data and use of both Table I and Table II data. This is shown in Figure 5-1.

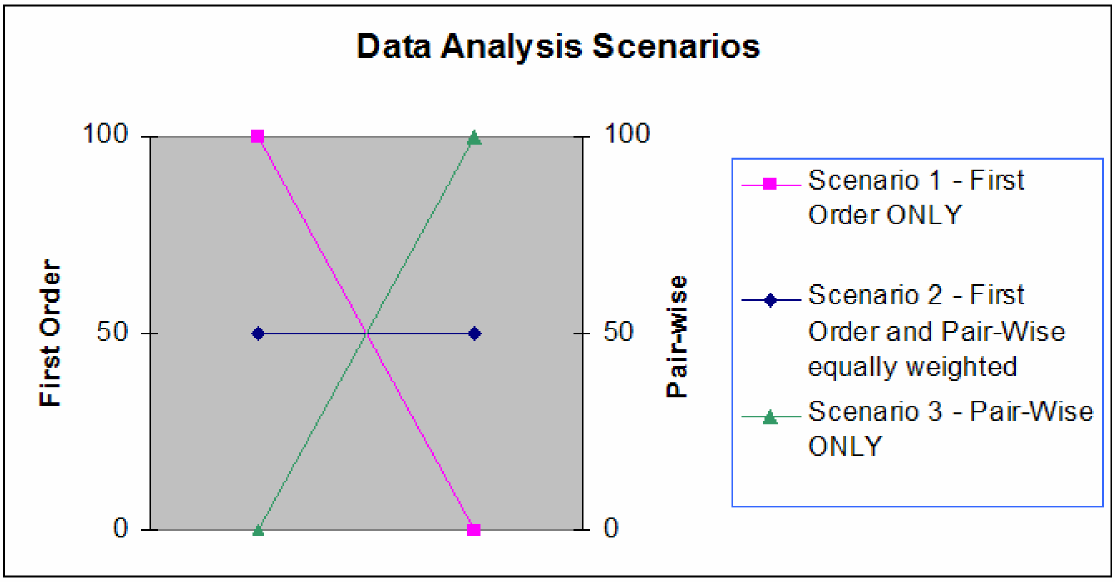


Figure 5-1 Three Scenarios for Survey Data Analysis

For scenarios 1 and 2, both of which use Table I data, there are 9 potential data sets. Five data sets are possible by analysing the 5 performance outcomes separately, but using ALL cases. This is shown as the '5 vertical cuts' in Figure 5-2. By calculating an equally weighted sum or average performance value for each characteristic, it is possible to analyse the results by tier. This means including for analysis only those cases relevant to the tier: Primes, 1st tier firms and 2nd tier firms. The final and ninth data set produces results for the industry by using the average performance value for ALL cases.

The assumptions in using an average or equally weighted sum, are that every performance criteria is equally important and that the ratings given by respondents reflect the relative magnitude of importance of the contribution to the performance criteria. This relative magnitude takes account of the longevity of the characteristic, its diffusion, and its cost. Rather than use a weighted sum, three-dimensional cluster analysis would be a possibility but not explored in this thesis.

	Product quality	Cost efficiency	Delivery precision	Technology/ innovation	Vision for the future	Calculated Equally Weighted Sum
.... (data removed for ease of explanation)						
5. Long-term relationship	5	7	5	5	9	6.2
6. Formal partnership	9	7	7	7	7	7.4
7. Subcontracting whole systems and sections	7	9	7	7	9	7.8
8. Flexibility of operations	3	5	9	3	7	5.4
9. Risk-sharing	0	9	0	7	7	4.6
10. Sharing knowledge	9	5	7	7	9	7.4
.... (data removed for ease of explanation)						
	QUALITY	COST	DELIVERY	TECHNOVATION	VISION	4 data sets: **1. all cases** 2. Primes only 3. Tier 1 only 4. Tier 2 only

all cases in each of the 5 vertical cuts

Figure 5-2 Part I Data Set Options

Scenario 2 takes account of both first order and pair-wise data *in equal measure*. The method used to consolidate pair-wise data for cluster analysis is described in Section 4.5 of this chapter (see sub-section 5.4.5). The assumption for this scenario is that first order and pair-wise data contribute equally to supply network performance data. This is an arbitrary choice: 90% first order and 10% pair-wise could have been selected, or vice versa or other combinations of ratios. Equal weighting was selected in order to take equal account of each, as the appropriate percentage is unknown and unknowable. It may have been possible to use a ranking of constructs to give further insight.

Scenario 3 uses only pair-wise data. The pair-wise data can be analysed only as four data sets: all cases, only those for Primes, only those for 1st tier firms and only those for 2nd tier firms. These four data sets enable comparison of patterns across tiers.

In total 22 data sets are analysed as shown in Figure 5-3 and so 22 data sets are presented to SPSS v16.0.0 for classification by hierarchical cluster analysis as described in the next section.

Part 1 (First Order Data)	Part 2 (Pair-wise Data)	Cases	Ref	Data Set
Product Quality (first column)	not used	All	1	First Order Quality
Cost Efficiency (second column)	not used	All	2	First Order Cost
Delivery Precision (third column)	not used	All	3	First Order Delivery
Technology/innovation (fourth column)	not used	All	4	First Order Technovation
Vision for the future (fifth column)	not used	All	5	First Order Vision
Weighted sum of all performances	not used	Primes	6	First Order Primes
Weighted sum of all performances	not used	Tier 1 firms	7	First Order Tier 1
Weighted sum of all performances	not used	Tier 2 firms	8	First Order Tier 2
Weighted sum of all performances	not used	All firms	9	First Order All
Product Quality (first column)	All data used	All	10	Joint Quality
Cost Efficiency (second column)	All data used	All	11	Joint Cost
Delivery Precision (third column)	All data used	All	12	Joint Delivery
Technology/innovation (fourth column)	All data used	All	13	Joint Technovation
Vision for the future (fifth column)	All data used	All	14	Joint Vision
Weighted sum of all performances	All data used	Primes	15	Joint Primes
Weighted sum of all performances	All data used	Tier 1 firms	16	Joint Tier 1
Weighted sum of all performances	All data used	Tier 2 firms	17	Joint Tier 2
Weighted sum of all performances	All data used	All firms	18	Joint All
not used	All data used	Primes	19	Pair-wise Primes
not used	All data used	Tier 1 firms	20	Pair-wise Tier 1
not used	All data used	Tier 2 firms	21	Pair-wise Tier 2
not used	All data used	All firms	22	Pair-wise All

Figure 5-3 Data Sets Analysed

5.4.4 Cluster Analysis

"*Cluster analysis seeks to group a sample of objects into homogenous classes on the basis of their similarity on M variables*" (Bailey, 1994: 34). It identifies configurations or clusters of similar variables which may not be evident from the objects themselves. Classification and the sorting of items into categories is central to research and explanation in a multitude of disciplines (McCarthy and Ridgway, 2000).

Items are classified into sets so as to describe patterns of similarities and differences in the data (Everitt and Dunn, 2001). The classification process or 'codification' (Meyer et al., 1993) reduces the complexity of the data allowing it to be more easily managed and better understood (Bailey, 1994). The process of clustering bundles variables (or cases) which are most similar (maximizing variable homogeneity) and creates bundles which are most dissimilar (maximizing cluster heterogeneity). Those variables in a cluster will have most similar questionnaire rating. Recognizing configurations or patterns via classification creates opportunity for sense-making (Ketchen Jr. and Shook, 1996) and for explanation of complex phenomena

(McCarthy, 1995). But classification is not explanatory although it may be used to form the foundations for explanation (Gordon, 1994).

The ontological status of classification differs between Realists and Nominalists. Realists give classifications ontological status, using classifications as a device for intervention, prediction and explanation. Nominalists understand classifications as abstract constructions which do not exist and are not observable (Blaikie, 1993) although the items belonging to the classifications exist. Regardless of the ontological status of classifications, the instrumentality of classification is its real test of utility (Everitt and Dunn, 2001). Accepting this notion of instrumentality means that appropriate variables can be selected based on the research problem.

A complex adaptive system is by definition changing and evolving; new characteristics appear, transform and drop out, resulting in different properties emerging from the system at different times. When we attempt to identify classifications for complex adaptive systems such as supply networks we must be aware that the classification is ephemeral and that the boundary of the classification is likely to be fuzzy. Prior to Darwin, classical biological classifications were based on natural types which were fixed. Darwin showed that species were not eternal and that they changed over time; boundaries are not sharp (Dennett, 1996).

Within the domain of research taking an evolutionary perspective, Systematics is used as an holistic method to classify organisms into taxa and resolve their evolutionary interrelationships over time by arranging taxa into a meaningful order (Sokol and Sneath, 1963). Similarity based on evolutionary relatedness is known as a phyletic (or longitudinal) relationship whereas similarity judged on characters alone is a phenetic (or cross-sectional) relationship (Bailey, 1994). Taxonomies are often hierarchical, attempting to describe empirically observed evolutionary states, in which cases are identical on all variables. This means that monothetic classes are created. In contrast, most classification contains polythetic classes in which cases do not have identical values on all variables. This research uses phyletic analysis in the creation of the supply network Cladogram and phenetic analysis for analysing the survey data.

The configurational approach to classification accommodates multidimensional ratings and generates polythetic classifications. Members of a group or cluster will share similarities across many dimensions or characters. The configurational approach somewhat refutes a reductionist argument by considering the cluster as a whole whose sum is greater than its component parts. Configurations will be a richer description of organizational phenomena and those derived deductively will perform better than those defined inductively (Ketchen Jr. et al., 1993). To temper their usefulness, they are only snap-shots in time, not saying anything about how the characteristics came to be similar, nor how they might diverge, consolidate, diminish or be replaced by other characteristics in the future. It is thus a static perspective within a larger research design, which as a whole aims to say something about the dynamics of supply networks.

5.4.4.1 Clustering choices

There are some 17 choices available for clustering provided by Bailey (1994). A review of the relevant decisions and choices is presented here.

The primary decision is to cluster the most similar characteristics (Q-analysis) rather than the most similar firms (R-analysis) (Bailey, 1994). SPSS facilitates this choice by clustering either ‘cases’ or ‘variables’. The raw data is collected such that the variables (R) are the rows. Each new case (Q) is in a separate spreadsheet initially and then combined to form the columns of the data sets. SPSS treats rows as cases, so the survey data is transposed in Excel (using the Paste – Special, Transpose function) and then copied to SPSS. In SPSS, ‘variables’ must be selected in the cluster function to identify clusters of similar characteristics. For the questionnaire survey, variables are clustered, so R analysis is performed.

The second choice in the clustering process is to select from one of two alternatives: compute measures of similarity (such as a correlation coefficient) or to compute measures of dissimilarity (such as distance measures). The Likert-type data collected in survey is treated as (quasi) interval data, so either measure can be used. Using distance measures means that objects already clustered are not affected by the addition of new objects to the analysis. This is important for the research as some characteristics are omitted from the clustering and it is necessary that their inclusion would not affect existing results. Euclidean distance measures are reported to provide consistently acceptable results (Milligan, 1994). Also the tree clustering method that generates the dendrogram uses distance measures. SPSS program guidance states that the most straightforward way of computing distances between objects in a multi-dimensional space is to compute Euclidean distances. The calculation is the geometric distance in the multidimensional space is shown by the formula in Equation 5-2.

$$\text{distance}(x,y) = \{\textstyle\sum_i (x_i - y_i)^2\}^{½}$$

Equation 5-2 Euclidean Distance

The Squared Euclidean distance was adopted in these analyses in order to place progressively greater weight on objects that are further apart. The equation for Squared Euclidean distance is shown in Equation 5-3.

$$\text{distance}(x,y) = \textstyle\sum_i (x_i - y_i)^2$$

Equation 5-3 Squared Euclidean Distance

Euclidean distances are usually computed from raw data and not standardized (normalized) data as proposed for this research. This means that if new variables, particularly ones of a larger scale, are added, they could greatly affect the clustering results. As no new variables (characteristics) will be added this is not an issue for this analysis. Note that post normalization (for example, by Z scores) which is an option for cluster analysis is not required and so is not selected within SPSS.

The third choice in cluster analysis is to select the method to amalgamate or link clusters. Once several objects have been linked together an amalgamation rule is needed to determine when two clusters are sufficiently similar to be linked. The default method in SPSS is within group linkages however three other methods commonly use squared Euclidean distances: Centroid (UPGMC), Median and Ward.

Unweighted pair-group centroid. For this method of clustering, the centroid of a cluster is the average point in multi-dimensional space (StatSoft, 2008). The distance between two clusters is calculated as the distance between their centroids (Sokol and Sneath, 1963).

Weighted pair-group centroid (median). As for the UPGMC except that a weighting is introduced to take account of cluster size, i.e. the number of objects in each cluster (StatSoft, 2008). The method is preferred if considerable differences in cluster size are expected.

Ward's method. This method minimizes the sum of square of any two (hypothetical) clusters that can be formed at each step. It uses an analysis of variance approach to evaluate distances between clusters and so is different from UPGMC and Median approaches (StatSoft, 2008). The method is very efficient but does create small-sized clusters.

The method of amalgamation selected is Ward's Method which has the best recovery performance (ability to identify clusters from raw data) of all methods, when used with Squared Euclidean measure of distance (Milligan, 1994).

Cluster analysis employs two technical methods: hierarchical and non-hierarchical. The hierarchical method groups individual cases into clusters based on similarity of variables, creating clusters with the greatest homogeneity. The non-hierarchical method assigns cases to groups established a priori. As the research is exploratory, the hierarchical method is used.

The choices and selections made for the cluster analysis have been stated here. The necessary checks for multicollinearity are described next.

5.4.4.2 Multicollinearity

Multicollinearity is present in a set of data where correlation amongst independent variables is strong. It is the extent to which a variable can be explained by other variables in the analysis. Where multiple correlation between one variable and a set of others is in the range of 0.9 or more, then multicollinearity is present (Norman and Streiner, 2000), and the variable should be removed.

All survey results were all tested to decide whether multicollinearity was present. Correlations were examined for each data set using the Correlate, bivariate function within SPSS©. Pearson's correlation was extracted as the data type is interval data. If two variables (characteristics) are highly correlated it could represent the double inclusion of one underlying dimension (Ketchen Jr. et al., 1993).

For all correlations >= 0.7, P <=0.001, >= 0.6 but < 0.7, P<=0.01, and < 0.6, P<0.1 (all using 2-tailed test). Three pairs of characteristics were moderately correlated. Within Data set 1 (Table 1, Quality ratings), characteristic 15 (high level of planning and control) has a correlation of 0.85 with characteristic 17 (IT system integration). Within Data set 4 (Table 1, Innovation/Technology ratings), characteristic 7 (subcontract whole systems) has a correlation of 0.89 with characteristic 10 (sharing knowledge) and characteristic 13 (can handle cultural differences) has a correlation of 0.86 with characteristic 16 (easy dialogue with supplier). No other correlations > 0.7 were revealed in the correlation tests for the other data sets.

It was decided to include all 27 characteristics for three reasons. First, specific pairs of characteristics (e.g. 13 and 16) were not highly correlated in other data sets. Second, the unique focus of each characteristic cannot be easily accommodated within any other characteristic as all characteristics are uni-dimensional. Third, the characteristics were developed from literature and validated empirically so they should be parsimonious but also complete.

Figure 5-4 shows a typical correlation report, including means and standard deviations.

Correlations

	mean	s.d.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	2.07	1.6																										
2	1.76	0.7	-.248																									
3	2.43	0.7	.140	.353																								
4	0.27	1.3	.122	.469*	-.277																							
5	2.69	1	.178	.434	.381	.369																						
6	2.24	0.5	-.449	.008	-.046	-.113	.255																					
7	1.94	1.1	-.173	-.251	.078	-.543*	.274	.553*																				
8	1.81	0.7	-.238	.117	.048	-.012	.356	.525*	.617**																			
9	1.85	0.9	-.293	.105	.315	-.120	.612**	.569*	.669**	.587*																		
10	2.16	0.9	-.254	-.070	.269	-.415	.226	.559*	.735**	.752**	.739**																	
11	0.76	0.6	-.085	.482*	.184	.378	.386	.061	-.149	.202	.365	.097																
12	2.22	0.8	-.106	.123	.311	-.274	.416	.392	.746**	.685**	.747**	.807**	.089															
13	1.51	0.7	-.422	.464	.278	.073	.565*	.598**	.459	.668**	.693**	.475*	.452	.508*														
14	0.77	1.2	-.167	.447	-.126	.500*	.061	.001	-.434	.078	-.101	-.240	.390	-.080	.332													
15	1.62	0.6	-.123	.456	.253	.199	.256	.250	.131	.345	.248	.324	.399	.390	.294	.306												
16	2.42	0.9	-.247	.541*	.284	.319	.491*	.265	.127	.532*	.356	.236	.306	.290	.720**	.431	.278											
17	1.55	0.9	-.082	.217	.303	.070	.296	.195	.272	.547*	.457	.596**	.533*	.519*	.393	.188	.778**	.383										
18	1.87	0.9	-.026	.016	.370	-.178	-.100	.072	.123	.482*	.206	.552*	.287	.354	.176	.114	.426	.413	.686**									
19	1.75	0.7	-.292	.194	.004	-.026	.043	.467	.413	.738**	.229	.612**	.134	.356	.399	-.036	.519*	.475*	.599**	.599**								
20	1.53	0.9	.087	.207	.330	-.045	.026	-.142	.159	.334	.244	.407	.278	.441	.253	-.063	.288	.222	.457	.478*	.271							
21	2.16	0.8	-.178	-.043	.099	-.122	.102	.684**	.486*	.481*	.469*	.700**	-.068	.486*	.313	-.292	.358	.051	.391	.227	.554*	.367						
22	1.89	1.1	-.553*	.347	.024	-.109	.160	.720**	.427	.452	.468	.491*	.051	.368	.612**	.061	.170	.460	.019	.115	.489*	.128	.497*					
23	2.38	0.6	-.622**	-.159	-.188	-.356	-.389	.561*	.296	.137	.166	.293	-.328	.046	.183	-.079	-.096	.138	-.202	.091	.307	-.081	.392	.733**				
24	1.76	0.8	.033	-.092	-.140	.126	-.575*	-.436	-.573*	-.085	-.479*	-.206	.071	-.426	-.309	.348	-.110	.071	.010	.466	.088	.207	-.274	-.179	.122			
25	1.93	0.9	-.729**	-.168	-.199	-.467	-.570*	.290	.201	.095	.092	.290	-.331	.082	.099	-.076	-.296	-.035	-.246	.092	.144	.012	.208	.505*	.784**	.174		
26	2.1	0.7	-.421	.123	.166	-.151	-.341	.237	-.056	.396	.089	.470*	.004	.258	.209	.254	.126	.265	.266	.640**	.414	.344	.354	.347	.375	.447	.604**	
27	1.75	0.7	-.552*	.471*	.261	.042	-.063	.403	-.075	.173	.171	.231	.157	.246	.329	.490*	.590**	.407	.333	.430	.312	.082	.239	.497*	.424	.106	.348	.614**

*. Pearson correlation is significant at the 0.05 level (2-tailed).

**. Pearson Correlation is significant at the 0.01 level (2-tailed).

Figure 5-4 Correlation Sample

5.4.4.3 Normalization (standardization of measures)

Distance measures are sensitive to the scales describing variables because these analyses utilise standard deviations and squared values (Hair et al., 2005). So prior to the import and manipulation of any raw data by a cluster analysis tool, values must be normalized. Normalization allows the responses from different individuals to be compared in a fair manner because the process of normalization brings the responses into a standard system. This means that the relative importance of the score to the respondent is reflected accurately and so is comparable with scores of other respondents.

A simple normalization process is used whereby the mean of all scores is divided into each score. As there are 27 characteristics, the sum of the normalized scores equals 27 and a score greater than 1 demonstrates an above average importance and a score below 1 reflects less importance.

The following example illustrates:

Respondent A: Gives high scores to most characteristics; this could be as a result of optimistic outlook, an opinion that the performance of the characteristics cannot be improved much more, or some other reason.

Respondent B: Gives quite low scores to most characteristics; perhaps as a result of pessimistic outlook, having high expectations for improvement, or some other reason. A subset of their scores is shown in Figure 5-5.

	Respondent A	Respondent B
8. Flexibility of operations	8	6
9. Risk-sharing	9	5
10. Sharing knowledge	7	6
11. Offsets as part of sales contract	6	4

Figure 5-5 Normalization of Ratings Example (before)

The average score for Respondent A is quite high at 7.5 and quite low for Respondent B at 5.3. Dividing each score by the average score for all performance criteria for each respondent has the effect of aligning the scores around the average of 1 in order to make comparison. This is shown in Figure 5-6 for the sample.

	Respondent A	Respondent B
8. Flexibility of operations	1.07	1.14
9. Risk-sharing	1.20	0.95
10. Sharing knowledge	0.93	1.14
11. Offsets as part of sales contract	0.80	0.76

Figure 5-6 Normalization of Ratings Example (after)

For characteristic 8, flexibility of operations, we now use a value for Respondent B which is higher than for Respondent A. This is because for respondent B, a score of 6 is relatively high whereas a score of 8 is not as relatively high for respondent A.

An extract of normalized results is shown in Figure 5-7. The first column contains the number of the characteristic which acts as its identifier. Each subsequent column represents a new case.

char							
1	1.52	0.96	0.78	0.82	1.24	0.55	etc.
2	1.37	1.02	0.88	1.04	1.1	1.13	
3	1.18	1.25	0.91	0.88	0.96	1.13	
4	0.38	0.45	0.95	0.51	0.78	0.68	
5	1.22	1.12	0.91	1.11	1.21	1.11	
6	0.99	1.12	0.91	1.2	0.92	1.13	
7	1.52	1.05	0.95	0.98	0.39	0.8	
8	1.03	0.99	1.15	1.14	0.71	0.88	
9	0.69	0.93	0.95	1.26	0.71	1.11	
10	1.26	1.34	0.98	1.17	0.6	1.13	
11	0.34	0	0.85	0.54	0.18	0.8	
12	0.95	1.15	0.81	1.2	1.06	1.08	
13	0.8	0.96	1.02	0.95	0.92	0.98	
14	0.04	0.96	1.25	0.82	1.28	0.9	
15	1.03	0.99	1.19	0.79	1.03	1.13	
16	1.14	1.09	1.05	1.2	1.42	1.13	
17	1.18	0.86	1.12	0.85	0.67	1.03	
18	1.1	0.89	1.08	0.79	1.14	1.11	
19	1.29	0.93	0.88	1.04	1.03	1.05	
20	0.8	0.77	0.91	1.17	0.71	0.73	
21	0.95	1.15	0.98	1.14	1.06	1.08	
22	0.91	1.05	1.08	0.98	1.28	1.08	
23	1.1	1.34	1.15	1.39	1.42	1.08	
24	1.22	1.09	1.05	1.33	1.31	0.98	
25	1.18	1.12	1.15	1.29	1.24	0.98	
26	0.95	1.31	1.02	1.17	1.42	1.13	
27	0.84	1.12	1.02	0.25	1.21	1.08	

Figure 5-7 Extract of normalized case results for sample Table 1 data

Normalization of the pair-wise matrix must follow a slightly different method since the scale of responses for the pair-wise matrix is in the whole number range -5 to +5. This is discussed in section 4.5.

5.4.4.4 Selection of characteristics

The normalized results for all 27 characteristics can now be supplied for cluster analysis. However, the inclusion of this large number of characteristics will detract from a focus on the important characteristics. For practitioners, there is a need to focus on those characteristics that are both important and agreed upon as valid characteristics. The coefficient of variation is used to exclude less significant characteristics as it takes account of both the mean and the standard deviation of the data set and is comparable across data sets (Black, 1999). The value of the analyses is not diminished since the location of insignificant characteristics within the cluster analysis output is not important and their exclusion does not affect the clustering results.

Each data set includes only those rows (characteristics) which have a coefficient of variation less than 0.5. This includes between ⅓ to ½ of characteristics which are the ones with high performance scores and with high agreement (and so low standard deviation). The selection process is carried out using the following steps. First, the appropriate normalized scores are selected (depending on the data set in question) and the average score for each characteristic in the data set is calculated. This mean score is an accurate reflection of the significance of the characteristic for the data set. A score of null or zero will bring down the average, leaving only those characteristics which are consistently scored highly to achieve a high average score.

The second step is to calculate the standard deviation of the scores as shown in Equation 5-4 employed using the STDEV function in Excel.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^2},$$

Equation 5-4 Standard Deviation

$\overline{x}$ is the arithmetic mean of the values x_i. This formula can be used since the data set consists of discrete random variables each of which has an equal probability.

The standard deviation function provides a measure of uncertainty. A low standard deviation indicates high confidence that most scores are close to the arithmetic mean. For a normal distribution, some 68.2% of population are within one standard deviation of the mean, 95.5% within 2 standard deviations and 99.7% within 3. This is shown in Figure 5-8.

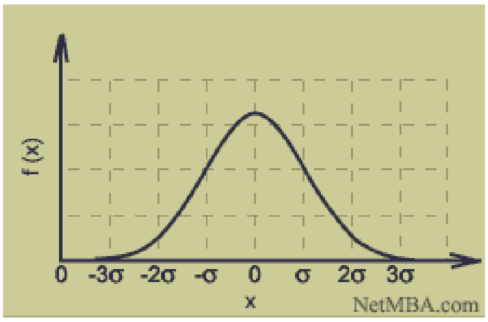


Figure 5-8 Standard Deviation of a Normal Distribution (www.netMBA.com)

A characteristic for which there is a high standard deviation means that there is low agreement with respect to the normalized average. Inclusion of such characteristics would reduce the validity of the results.

The third step is to calculate the coefficient of variation. This is the ratio of the standard deviation to the mean and is a dimensionless number which can be used to compare the amount of variance between populations with different means. The coefficient of variation is a measure of dispersion of a distribution and is calculated by dividing the standard deviation by the average score as shown in Equation 5-5.

$$c_v = \frac{\sigma}{\mu}$$

Equation 5-5 Coefficient of Variation

This approach favours both high averages and low standard deviations. The lower the coefficient of variation, the more confidence we might have in its validity.

The effect of different standard deviations and mean scores is shown in Figure 5-9. A low standard deviation and a high mean score is always favoured in this regime and is the required approach for inclusion of characteristics in the analysis.

Std Deviation	Mean Score	Effect on Coefficient of Variation
High (low validity)	High	A high standard deviation (high disagreement in scores) is moderated somewhat by a high mean (high importance).
Low (high validity)	High	A low standard deviation divided by a high mean creates a smaller coefficient of variation. These characteristics are important and there is high agreement as to their importance. **CHARACTERISTICS WITH THESE SCORES ARE ALWAYS INCLUDED**
High	Low	The low mean score exacerbates the effect of a high standard deviation. These are unimportant characteristics which have low agreement between respondents.
Low	Low	A low mean reduces the effect of a low standard deviation. Whilst the characteristic may not be a high contributor to the Performance Criteria, it is of high validity and should be included.

Figure 5-9 Coefficient of Variation examination

The final step is in the selection process is to include only those characteristics which have a coefficient of variation less than 0.5. This is achieved by sorting the data set in ascending sequence of the coefficient of variation so that the top row of the output sort shows the most significant factor. Characteristics with a coefficient of variation greater than 0.5 are excluded from the cluster analysis and account for around half of the data.

5.4.4.5 Weighting, Outliers, and Validation

The presence of outliers, that is cases which are very different from the majority of other cases, was not examined since Ward's Method is resistant to the presence of outliers (Hair et al., 2005).

Validity has been tested by two heuristic methods: the split-half test and comparison of variable means across clusters against the variable mean for the full data set. Some statistical techniques which attempt to verify the clusters have been discounted because of concerns as to their validity (Aldenderfer and Blashfield, 1985), so these heuristic methods provide a reasonable assurance that clusters do exist and that appropriate variables are in each cluster.

Of the 22 data sets in the survey analysis, 13 data sets use all cases. For these 13 data sets, split half tests were carried out and variable means were examined. The results relating to one data set selected at random is shown in Appendix J. Testing to ensure that clusters can be replicated by other means was completed by examining variable means. When variable means are significantly different across clusters and from the grand mean, then cluster distinctiveness is indicated (Black, 1999). The results confirmed that the variance in variable means within-cluster is minimised and between cluster variance is maximised, as well as being separate from the full data set mean.

The variables in each split half cluster are the same variables which cluster in the full data set and so replication has been achieved using split half methods. Split-half and the variable means test results are a good indicator that the clusters found are valid. In addition, since the survey forms only one method of producing results which contribute to the overall study, the specific validity of these clustering results in isolation is less of an issue.

5.4.5 Data Preparation Process for Pair-wise Data

5.4.5.1 Pair-wise data

This section refers to the analysis required for Part II of the survey response – the pair-wise matrix. The objective of the data preparation process for pair-wise data is to create a single column of data with 27 rows. The resulting value associated with each row/characteristic represents a consolidation of the effects of every characteristic upon the characteristic in question.

Each respondent was asked to complete 'half' a pair-wise matrix. Each cell requires a rating to describe the effect of two characteristics upon each other. Each cell quantifies the degree of synergy or conflict between a pair of characteristics. By this we mean that either two practices are mutually "helpful" and reinforce each other (synergetic), or on the contrary, they are mutually exclusive and conflict with each other (conflicting). Values permitted are: +5, +4, +3, +2, +1, 0, -1, -2, -3, -4, -5. If two practices are strongly synergetic (or reinforcing) a response of +5 is required in the cell that joins up these two practices. If the pair of practices have a neutral effect or are independent of each other, then a score of 0 should be supplied. If two practices conflict or have a severe weakening effect upon each other then a score of -5 would be relevant. An example of a completed pair-wise matrix is shown in Figure 5-10.

Characteristics Strongly synergetic (+5), indiffernt effects (0), strongly conflicting (-5)	1. Outsourcing competitive advantage	2. Outsourcing what is easily imitated	3. High level of collaborative relationship	4. Arms length relationship	5. Long-term relationship	6. Formal partnership	7. Subcontracting whole systems and sections	8. Flexibility of operations	9. Risk-sharing	10. Sharing knowledge	11. Offsets as part of sales contract	12. Culture of continuous improvement	13. Ability to handle cultural differences	14. High level of dominance over supplier	15. High level of planning and control	16. Easy dialogue with supplier	17. IT system intergration	18. High levels of integration in chain	19. Responsive to market change	20. Transparent organisation	21. TQM procedures	22. Just-in-time delivery	23. Lean practices	24. Explorative learning prac	25. Investment in trainin	26. Supplier devel
2. Outsourcing what is easily imitated	4																									
3. High level of collaborative relationship	-4	4																								
4. Arms length relationship	-5	2	-5																							
5. Long-term relationship	5	4	5	-1																						
6. Formal partnership	5	3	4	-5	5																					
7. Subcontracting whole systems and sections	3	3	5	-3	4	4																				
8. Flexibility of operations	4	4	3	-2	-3	-2	-4																			
9. Risk-sharing	5	-3	5	-5	3	5	0	-4																		
10. Sharing knowledge	5	0	5	-5	5	3	-2	4	5																	
11. Offsets as part of sales contract	0	4	0	0	0	3	0	-3	2	0																
12. Culture of continuous improvement	-5	-1	5	-3	4	3	0	5	3	0	-1															
13. Ability to handle cultural differences	0	0	3	0	4	3	0	4	0	5	1	5														
14. High level of dominance over supplier	5	-2	-5	2	0	-5	0	-3	-5	-4	0	-4	0													
15. High level of planning and control	4	2	3	2	-4	-4	-4	-2	-3	0	0	0	0	4												
16. Easy dialogue with supplier	4	3	5	-2	4	3	0	4	4	5	0	5	5	2	-1											
17. IT system integration	0	0	3	-3	0	3	0	-4	0	0	0	-4	1	4	3	-2										
18. High levels of integration in chain	5	3	5	-2	3	4	2	3	0	4	2	2	3	0	3	2	4									
19. Responsive to market change	-4	3	4	0	0	0	-2	5	-3	4	-3	3	0	-5	2	-3	-4	3								
20. Transparent organisation	4	2	5	-4	2	2	0	3	3	5	0	3	3	-3	0	5	2	4	5							
21. TQM procedures	0	3	3	-3	0	3	0	-3	0	0	0	2	0	0	0	0	3	3	1	3						
22. Just-in-time delivery	0	5	3	0	0	0	0	4	0	4	-3	4	1	0	2	3	-2	5	4	4	3					
23. Lean practices	-5	4	5	0	2	3	0	5	4	5	-3	5	4	2	-2	4	-4	5	5	5	4	5				
24. Explorative learning practices	5	-2	5	-4	4	4	3	4	4	5	3	5	5	-3	0	5	-4	5	4	4	2	3	5			
25. Investment in training	-3	3	4	-5	3	3	-2	4	3	3	2	4	3	-3	3	3	0	4	4	4	3	3	4	4		
26. Supplier development	4	3	4	-4	3	4	0	3	4	4	4	4	3	-3	4	4	0	5	5	4	4	4	5	5	4	
27. Monitoring suppliers	4	3	2	-3	2	1	4	3	2	1	4	3	0	5	5	3	3	0	0	5	2	2	1	2	0	0

Figure 5-10 Sample Pair-wise matrix

The assumption in requiring only ‘half’ of the matrix to be completed is that each characteristic had the same magnitude of effect regardless of the order in which the characteristic was adopted. That is, the characteristics have a symmetrical effect upon each other. This assumption is a small limitation of the research study.

The effect of this strategy within the context of the current research relating to 27 characteristics is that respondents complete 26 + 25 + 24 …+ 1 cells, a total of 351 cells, compared to a full 27 x 27 matrix, excluding the diagonal (-27) which would be some 702 cells.

5.4.5.2 Method for calculation of pair-wise effects

Matrix multiplication is the method used to calculate the inter-characteristic effects (Allen et al., 2008a). The effect of matrix multiplication is to find the total effect of a characteristic upon every other characteristic. The mathematical process of matrix multiplication takes two input matrices and calculates an output matrix. For this research study the two input matrices are the same and constructed from the pair-wise survey data. The effect of the matrix multiplication and its relevance is discussed below. The calculation of matrix *a*, which is the product of two input arrays *b* and *c* is shown in Equation 5-6. *i* is the row number, and *j* is the column number.

$$a_{ij} = \sum_{k=1}^{n} b_{ik} c_{kj}$$

Equation 5-6 Matrix Multiplication

Each cell in the output matrix *a* contains the sum of the products of the pair interactions. This explanation is more easily grasped visually by providing an example. Matrices *b* and *c* are the same because the desired outcome is the matrix multiplied by itself. Note that the diagonal is zero in accordance with our assumption in the research study that a characteristic has no effect upon itself. Figure 5-11 shows an example with the diagonal of matrix *a* containing the results of interest to the study. The result for characteristic 2 (=65) is contained in cell (2,2) of the output matrix *a*, is the sum of the products of the pair interactions in row 2 of the input matrix *b* and column 2 of the input matrix *c*.

matrix b			
0	5	4	3
5	0	6	2
4	6	0	1
3	2	1	0

Matrix Mult.

matrix c			
0	5	4	3
5	0	6	2
4	6	0	1
3	2	1	0

=

matrix a			
50	30	33	14
30	65	22	21
33	22	53	24
14	21	24	14

cell a(2,2)			
5	5	25	+
0	0	0	+
6	6	36	+
2	2	4	+
	=	65	

Figure 5-11 Matrix Multiplication Sample

The effect of the matrix multiplication is to give more weight to larger scores. For example, if a respondent gives the scores 1, 3 and 5 to three different characteristics, the effect is that the characteristic with a score of 1 is 25 times smaller than the characteristic with a score of 5, and 9 times smaller than a characteristic with a score of 3. This effect is helpful and reflects to some extent the fact that interaction and feedback often creates non-linear and sometimes runaway effects on performance.

A complication arises with matrix multiplication due to the nature of the research problem in that pair-wise ratings can be negative. We require the matrix multiplication result to reflect a reduction if a cell is negative. This is achieved by using the absolute value (ignoring the sign of the rating) when making the input matrix symmetrical. An example is shown in Figure 5-12 whereby all cells in the source data are negative to show that the result in Figure 5-11 can be delivered. In the actual data collected, there is a mixture of positive and negative data, and the scheme works for either as addition is commutative.

matrix b			
0	5	4	3
-5	0	6	2
-4	-6	0	1
-3	-2	-1	0

Matrix Mult.

matrix c			
0	5	4	3
-5	0	6	2
-4	-6	0	1
-3	-2	-1	0

=

matrix a			
-50	-30	27	14
-30	-65	-22	-9
27	-22	-53	-24
14	-9	-24	-14

cell a(2,2)			
-5	5	-25	+
0	0	0	+
6	-6	-36	+
2	-2	-4	+
	=	-65	

Figure 5-12 Matrix Multiplication Sample 2

Having made the assumption that the effect of any characteristic *x* is the same upon any characteristic *y* regardless of the order in which the characteristics are adopted, we need to construct a full matrix by using the transpose of the source matrix. Microsoft Excel® incorporates a function to do this: Copy, Paste Special, Transpose. A full matrix can then be constructed using the source data, zeros along the diagonal and the absolute values in the transposed half of the matrix, in order to accommodate negative values described above. The newly formed matrix can then be multiplied by itself to create the output matrix. The formula adopted is shown in Equation 5-7.

$$(M+|M^T|) \text{ matrix multiplication function } (M+|M^T|) = \text{output Matrix}$$

Equation 5-7 Matrix Multiplication Formula

The diagonal is moved into a single column, and used as the source data for Table 2.

The detailed steps undertaken to manipulate the input pair-wise data in order to calculate pair-wise effects is shown fully in Appendix K.

5.4.5.3 Normalization

In the same way that normalization of first order data is required, normalization of pair-wise data is needed to allow fair comparison of cases. The matrix multiplication process creates a single score for each characteristic (using the results in the diagonal). The average of all scores is calculated and divided into each characteristic value.

Some characteristics scored a negative overall value. The standard normalization process above is not sufficient to accommodate this. The absolute value of the matrix multiplication output must be used to calculate the average of all scores. Once normalized, any negatively rated characteristics can be multiplied by -1. If this process is not completed in this way, it is not a 50:50 comparison to the first order results which was the requirement for Scenario 2 (see Figure 5-1).

5.4.6 Cluster Analysis Process

The data supplied to SPSS was sorted in ascending sequence of the Coefficient of Variation. This means that the highest performing characteristic was ordered into first place. The numbers in the column headed ‘Num’ in the dendrogram indicate this ordering position of the variable when supplied to SPSS. An example is provided in Figure 5-13. Number 1 (characteristic 10 – char10 – in this data set and which indicates ‘sharing knowledge’) has the smallest Coefficient of Variation (0.199 which is not shown in the dendrogram) and has the greatest significance; Number 14, the lowest number in this data set (char19 which is ‘responsive to market change’) has the highest Coefficient of Variation in the data set at 0.499 and is the least significant in the data set (but still more important than the remaining 13 characteristics excluded from the cluster analysis).

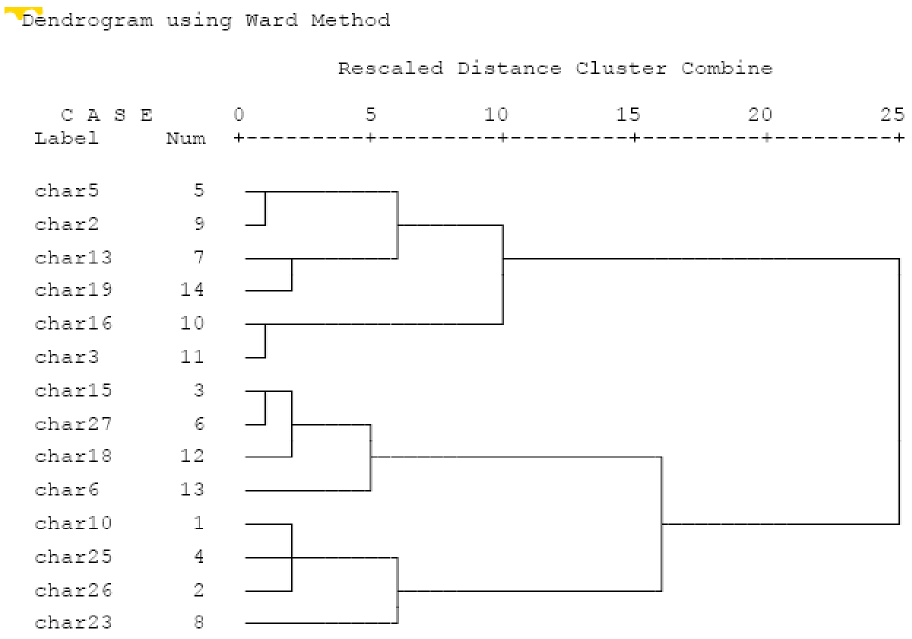


Figure 5-13 Example Dendrogram

Visualization of the clustering results is usually by dendrogram. A dendrogram is a tree drawing (taken from the Greek for *dendron* – tree and *gramma* – drawing). Dendrograms demonstrate the proximity of variables and the order in which particular variables cluster. The dendrogram example in Figure 5-13 is used here to describe the interpretation of clustering analysis carried out in Chapter 7. In this example, there are two main clusters: the first includes the first 6 variables – from char 5 through to char 3 inclusive; the second cluster contains the remaining 8 variables from char15 through to char 23 inclusive. The first main cluster has two sub-clusters, the first of which has four variables and the second with two variables. We see from this that char5 and char 2 are very similar, and that char13 and char19 are very similar, as are char16 and char3. However, all 6 variables would be found together in the main cluster which clusters at the point 10 on the horizontal scale. The variables in this cluster are therefore closer together than the variables in the second main cluster which cluster at point 16. Variables in a cluster are similar to those in the same cluster and different from those in another cluster. The distance to another cluster is given by the linkages which are measured on the horizontal scale. When characteristics are found that are close together, it indicates that many respondents rated these characteristics in a similar way to each other.

5.5 Ethical matters

Ethical matters have been reviewed during the development of this research. The Cranfield Ethics Questionnaire was completed prior to interviews and has been re-examined for its validity. Interviewees were presented with a statement regarding confidentiality prior to interview as follows:

1. "Your participation is much appreciated but it is voluntary and you may withdraw at any time for any reason.
2. Information privacy will be recognised at all times. Data will be treated with full confidentiality. It will be stored so that neither you nor your company will be identifiable.
3. Data will be used for research purposes only. Funding for the research is solely from the Research Body. We have no sponsors and there are no ulterior motives for the questioning.
4. There is no intention to deliberately withhold information about the research, nor to deceive or mislead you.
5. There is no foreseeable risk of distress or discomfort in your participation in this interview but some of the topics we discuss may provide stimulation for discussion with colleagues.
6. Normal privacy will be respected. You may decline to answer particular questions.
7. Analysis information will be made available to your company but it will be completely anonymised.

May I have your informed consent to continue?"

5.6 Summary

This chapter has provided details of the Research Design for the three stages of the Research Study. The first stage, a comparative case study of the three largest aerospace manufacturing firms, was historical and used public-domain information, primarily the CEO reports within published annual reports. The second stage, via interview, collected empirical data from firms located at 3 tiers in the aerospace supply network. The purpose of this stage was two-fold: 1. to validate inter-organizational characteristics identified from literature review (described in Chapter 7); 2. to obtain rich contextual information for each case achieved using a variety of interview methods (open-ended, semi-structured and structured (repertory grid technique). The third and last stage was a questionnaire survey rating the 27 characteristics validated in stage 2. The survey results were analysed using cluster analysis. The purpose of this stage is to present a means of describing the dynamics and structure of the supply network.

This chapter answered research question Q2b: "*What research design will provide insight and make a contribution to knowledge*?" It delivered the following expected outcomes:

- Research strategy
- Research design, with data collection phases
- Statement of analysis methods for each research stage

The actual data collection was completed at various points starting in 2004 for the historical case study, through the 2008 for the final questionnaire surveys.

The next chapter presents the case study results and Chapter 7 contains the cluster analyses.

6 AEROSPACE CASE STUDIES

"I think it (the supply network) is integrated. I think that, much more connected throughout the whole. I mean the awareness of the value chain is much greater. The influence or the impact on each other is much better understood. The decisions that are made are not in a vacuum. They are in consideration of the whole picture. It is global, it is anywhere in the world, 24 hours a day, 7 days a week."

Interviewee M
Commercial Aerospace Prime

6.1 Introduction

This chapter presents two sets of results relating to stages 1 and 2 of the research design. The first set of results relating to stage 1 is a case study of the three largest firms in aerospace manufacturing. This case study is already published (Varga and Allen, 2006) but forms the initial study on the aerospace industry and so is the starting point of the research for the thesis. The second set of results relating to stage 2 is the in-depth analyses of four firms in commercial aerospace manufacturing. Public domain information is used for stage 1, whilst stage 2 results which are based entirely on original interview data. The firms analysed in stage 1 are Boeing, Lockheed and EADS (Airbus) and for the purposes of confidentiality, the firms are not explicitly identified in the stage 2 results. Data collection, interview and analysis methods have been described in detail in chapter 5, so this section presents only the case study results. Chapter 7 presents the data analysis results for stage 3 of the research design which relates to the survey. Chapter 8 presents conclusions as part of a comparative analysis of results from all stages.

6.2 Stage 1 Results – A Case Study of the Three Largest Aerospace Manufacturing Firms

The case study summarised in this section (Varga and Allen, 2006) was carried out in 2004 and published in 2006. It has since been cited twice in peer-reviewed papers. Pathak et al (2007) note it as an example of a case study approach to complex system analysis, and Arranz and de Arroyabe (2008) note the relevant contribution of the paper to identifying complexity to the development of joint projects. The full published paper is reproduced in Appendix O and so only a summary is provided here.

The two primary sectors in the aerospace industry are commercial and defence aviation. Each sector is dominated by two key firms: Boeing and EADS (largely Airbus) in the commercial sector and Boeing and Lockheed Martin in the defence sector (Aerospace Innovation and Growth Team, 2003). Boeing obtains roughly half its revenues from each sector changed markedly since 1993 when 80% was generated from the commercial market. Lockheed Martin makes most of its revenue from defence and most of EADS's is commercial. In each of the sectors, there is a duopoly in power, although as noted in Chapter 2, Russia and China are beginning to develop their own jetliners.

CEO statements in the Annual Reports of each of these firms are examined in detail in order to compare their relative evolutionary potential. A tripartite approach was taken in the case study, examining strategy, innovation and organization within each firm. The strategic perspective assesses the clarity of each firm's long-term goals, resource alignment to long-term goals, the extent of adaptability of the strategy and whether the emphasis in strategic focus is on content (structure) or process. An innovation framework (Adams, 2003) which classifies innovations into one of three types based on their characteristics is used to analyse innovations (product and service) mentioned in each firm's Annual Report. The organizational perspective is based on my interpretation of firms as complex systems. The evaluation is based on fluctuations that exist within and outside the firm, attractor basins (or possible archetypes), variety of the firm's resources, the interactions between culture, technology and strategy, the capacity of the firm to innovate, and how its organizational form helps it innovate.

The paper presents an in-depth analysis using this tripartite approach and concludes:

"EADS appears to be placing most energy into evolution, and is most process focused in its strategic outlook. As such, it may evolve most significantly. In particular, developments as a consequence of its 555-seater plane, and its push for defence market share provide significant

latent potentials. Boeing is likely to stagnate in the short to medium-term as it redefines its corporate identity under new leadership. Its commercial market operational focus and innovation portfolio is inhibiting significant innovation. Lockheed Martin is currently evolving successfully because of defence market demand, but this is likely to peak and may contract in the long-term. Civil government and integrated solutions could provide Lockheed's new evolutionary pathway." (Varga and Allen, 2006: 62).

This case study explored the evolutionary potentials of the three largest aerospace manufacturers by evaluating strategic focus, innovation portfolio and organizational potential for evolution. Both within-case and cross-case evaluations were carried out based on public information within Company Annual Reports and as such there exist limitations to the generalisability of the research. In addition there was no access to these firms at this time in order to verify or dispute any of the conclusions, however the same conclusions could be reproduced independently using the stated tripartite approach, as the data is available for public inspection. Other limitations and further research are defined in the published paper and further reflection is provided in Chapter 8.

6.3 Stage 2 Results – Empirical Case Studies

The remainder of this chapter presents four detailed case studies of firms in the commercial aerospace sector. Multiple interview methods and multiple interviews using the same method were used in each firm as described in Chapter 5. The case studies are presented in the following order: Commercial Aerospace Prime; First Tier OEM/systems integrator OEM(A); First Tier OEM/large multi-national OEM(B); 2nd tier UK manufacturer SecondT. Firm identities are anonymised for confidentiality purposes.

6.4 Commercial Aerospace Prime

This firm is a world leading aerospace company and a major manufacturer of commercial jetliners. The wider corporation which owns the Prime is diversified into related defence and space/satellite fields, as are the corporation's main competitors. Commercial jetliners, defined by a passenger carrying capacity of 100 or more, are sold to customers around the world, so it is a large exporter in terms of sales. It employs over 150,000 staff around the world and has around 6,000 suppliers. It has well-established jetliner families of products, with modest numbers of current variants.

6.4.1 Results for the prime

The coding of interview transcripts with a total of over 25,000 words identified four core categories:

- Globalization
- Specialization
- Partnership
- Innovation

Two types of enabler and two types of constraints were also found. The enablers are: Information Communication Technologies and Standards. The constraints are own Government restrictions and lack of economic development in purchasing countries.

Each of the four core categories are broken down into sub categories as shown in Table 6-1 and described in detail in the following sub-sections. The relevant source interview transcripts are shown in Appendix L.

The next sub-sections describe how the firm and supply network is perceived through the eyes of the interviewees, and demonstrate how text has been coded to core categories and sub-categories.

Core Category	Sub Category
Globalization: the phenomenon of global connectedness for the purposes of access to skills for innovation, dealing with increasing product complexity, low costs, global markets	**Access to Skills:** Decline in numbers of aerospace engineers in the West. New skills will be found in increasing numbers of graduates in the East and South America. **Product Complexity:** Jetliners are no longer made from simple products sourced locally but complex products and services requiring 'smart people' all over the world. **Low Cost:** Access and availability of low cost products. **Competition:** There is no longer national loyalty. Competition is global so need to sell globally.
Specialization: the increasing focus and consolidation of suppliers into firms offering specific product systems or products, which are sold to many customers in many industries; airlines leaving finance/ownership to leasing companies	**Consolidation:** Focus on product system specialization has led to consolidation of suppliers. Strategic supplier drive by Prime has diminished numbers at 1st tier. **Demand Fluctuation:** Large waves of changes in demand driving suppliers to diversify into other markets. **2nd tier Specialization:** Specialization is by Prime rather than product system. **Jetliner Ownership:** Airlines are no longer the owners of jetliners, largely it is the leasing companies; maintenance and repair are, as a result, sub-contracted elsewhere.
Partnership: the independence of suppliers leading to risk-sharing between the Prime for strategic partners; collaboration to assure quality, technology integration and management of risk	**Vertical Disintegration:** Prime is no longer vertically integrated and do not own many suppliers, except where relevant risk is involved. **New Product Introduction:** Long time span between introductions; selected 1st tier suppliers staying for the duration of the product life. **Quality Management:** Maintaining and improvement of quality standards is critical and drives supplier selection. **Information Sharing:** More information could be shared with suppliers to avoid revisions, this is balanced by time to production. **Risk Management:** Mitigation of risk of Partner failure is of mutual interest and strikes a balance between cost to mitigate and to recover.
Innovation: the drive to invent, trial and implement new products and new processes which improve existing performance, permit customization, manage the risks inherent in new technologies and create new services	**Manufacturing Processes:** Whether a new jetliner or ongoing production of existing jetliners, continuous improvement is embedded. **R&D:** New technologies are easier to implement on new jetliners. Collaboration with suppliers can target R&D to improve existing technologies. **Network Performance:** Trial and error is part of the collaboration process in the attempt to find the right mix of suppliers for supply network evolution. **Risk Management:** Technology leadership is risky so managed as a risk by close monitoring of product success. **Product Services:** Post delivery product services are becoming a realizable opportunity.

Table 6-1 Core Categories in the Supply Network perceived by the Prime

6.4.2 Globalization

Globalization, the phenomenon of global connectedness, has been embraced by the commercial aerospace prime. There are four main aspects to its adoption. First is access to skills which are in scarce supply in the West but growing in the East and South America. Second is dealing with increasing product complexity. Third is access and availability of low cost products. Fourth is the need to compete with other Primes across the world since national airlines are now buying globally. These four aspects to globalization are presented in the remainder of this sub-section.

6.4.2.1 Globalization and access to skills

The diminishing and narrow diversity of aerospace engineers in the West is identified as a risk for the Prime, particularly as countries in the East have new and growing skills which will move the locus of innovation. There are very few new individuals coming to the aerospace industry. Engineering graduates choose different industries, so the same existing aerospace engineers move between firms. Skills need to be found globally. The prime has established educational relationships around the world to develop skills relating to the Prime's products and to mitigate the dearth of new graduates. These establishments and universities across the world which have close relationships with the Prime act as a source of new ideas, a means to develop skills for local suppliers, internships and jobs for individuals, and learning for universities.

6.4.2.2 Globalization and product complexity

Supply networks have changed from using local resources to create simple products to global resources for complex products and services. This has driven the search for resources and skills around the world. The longevity of jetliners, designed for a long product life (around 15 years), is also increased so spares and parts need to be available for a longer period. The Prime must be even more mindful of usage when it produces new variants of existing models and phases out old variants, so that current parts are compatible with older variants.

6.4.2.3 Globalization and low cost

The availability of products around the world (and the knowledge that these products exist and can be transported) means that the lowest price can be sourced from increased locations. And low cost is the driver for globalization. But with lower cost comes firm immaturity with respect to other capabilities, such as quality and delivery precision.

6.4.2.4 Globalization and competition

The loyalty of airlines to home country manufacturers has changed over the last 30 years. Nowadays, there is global competition for local customer business. The firm has had to lose some of its arrogance and evaluate the reasons for customers choosing to buy elsewhere. This has been difficult to learn but is now embedded for the benefit of future managers in the firm.

6.4.3 Specialization

The increasing specialization of suppliers into product systems or specialist products indicates a move away from the generalist firm. The specialist firm is increasingly perceived as a systems integrator or OEM who is likely to have many customers for their specialist product, and to be diversified into other industries. Aspects of specialization identified include consolidation of suppliers, managing demand fluctuation, 2nd tier supplier specialization and changing jetliner ownership.

6.4.3.1 Specialization and consolidation

The need for 1st tier suppliers to deliver complete assemblies or systems has driven consolidation in the market place, bringing together suppliers making parts for the same system. The numbers of suppliers is reduced by a factor of around 10 for the Prime.

6.4.3.2 Specialization and demand fluctuation

Customer demand for jetliners halved in a three year period then recovered in a three year period witnessed between 2000 and 2008. The effect on suppliers, particularly suppliers of key commodities, is that they need to be diversified into other markets for their commodities so that they do not become liable to bankruptcy. This diversification leads to new customers able to exert power, creating pressure for timely delivery of the commodities demanded by the Prime.

6.4.3.3 Specialization and 2nd tier

Suppliers to the first tier OEMs/systems integrators are likely to line up with one or other of the primes, and so specialize in their particular products. The number of alternative suppliers at 2nd tier is thus fewer but is airframe specific, in contrast to first tier suppliers who make products for any jetliner.

6.4.3.4 Specialization and jetliner ownership

The owners of jetliners are no longer the airlines who have been loyal to the prime. This means that finance and leasing companies have become owners, through these arrangements. The effect is that the maintenance and repair operations can be subcontracted elsewhere and not back to the commercial aerospace prime. Earnings for the commercial aerospace prime which traditionally resided in maintenance and repair have shifted to the sale of the product.

6.4.4 Partnership

The move from vertically integrated, prime controlled suppliers, to the independence of suppliers has markedly changed the nature of the supply network. The need for more collaboration and risk-sharing is evident. This core category of partnership encompasses five aspects: vertical disintegration and partnering consequences; new product introduction and the longevity of suppliers in established supply networks; quality management and the continual raising of standards; information sharing and its timeliness; and finally risk management related to supplier failure.

6.4.4.1 Partnership and vertical disintegration

The commercial aerospace prime as transformed from being vertically integrated to having a smaller set of suppliers. Most manufacturing is no longer carried out by the prime. The suppliers who are selected are likely to specialize in all aspects of the particular product they produce. However, if the Prime supports a supplier to design a unique product, then the Prime will want to own the risk and so will acquire the supplier.

6.4.4.2 Partnership and new product introductions

The inception of a new jetliner is the opportunity to identify suppliers with the capabilities, particularly technological, to deliver the programme. Criteria are increasingly stringent and broad, because the Prime and these first tier suppliers stay together for the duration of the production of the jetliner. Whilst new technologies are needed in new jetliners, the manufacturing of existing jetliners continues fairly unchanged throughout its potentially long production years. This stability in the product is constrained by certification and by powerful customer demand for consistency between model variants.

The time span between new product introductions can be as long as the life-span of a jetliner and is thought to be difficult to shorten. If a product introduction happens to coincide with increased demand for existing jetliners, then the supply base can be stretched, as suppliers are likely to contribute to the production of both.

6.4.4.3 Partnership and quality management

Expectations of 1st tier suppliers have never been higher, particularly of risk-sharing partners. Support is given by helping the supplier perform more highly for the benefit of both the Prime and the supplier. Suppliers to the Prime are identified by quality badges, so that the highest quality suppliers are offered work first. Increased performance has often been driven by industrial change, particularly in automotive, and the use of lean techniques.

6.4.4.4 Partnership and information sharing

Sharing of information with the supplier is piecemeal but is more effective at progressing production, albeit with the need for changes through out. This can be favourable to the supplier as changes can be charged. The main competitor to the prime, shares all the information, so the supplier is less likely to need to change, but this creates delay in establishing production. Nevertheless more information sharing is thought to be needed by the Prime.

6.4.4.5 Partnership and risk management

Limited numbers of suppliers are available for most parts and whilst double sourcing is possible, it is not cost effective for the management of operational risks. There needs to be a balance between risk and cost to mitigate risk. In terms of suppliers, their risk of failure or bankruptcy is a risk to the Prime, so risk in managed by understanding mutual interests and responsibilities in a partnership capacity. Partnering also helps to influence sales and to create shared investments.

6.4.5 Innovation

Innovation is the fourth core category of this case study. It encompasses the drive evident within the Prime to invent, trial and implement new products and new processes using new technologies and techniques. There are five aspects to innovation. First, continuous improvement in the manufacturing process is enabling increased product turns and reduced waste. Second, R&D collaboration with suppliers is creating ‘blurred technology’ targeted in ways to benefit both the Prime and the supplier. Next, trial and error is part of the collaboration process in the attempt to find the right mix of suppliers for supply network evolution. Fourth, the Prime balances technological leadership with risk management. Last, innovation in product services post delivery is becoming a realizable opportunity.

6.4.5.1 Innovation and manufacturing processes

Jetliners need to be produced more quickly and with less waste, which requires close relationships with 1st tier suppliers. The relationship is no longer prescriptive and much more a matter of continuous improvement regardless of whether it is the development of a new programme or the ongoing production of an existing jetliner model.

6.4.5.2 Innovation and R&D

New technologies are much easier to adopt on new jetliners, but suppliers will invest R&D funds on technology research which may not be usable for some time. Collaboration with suppliers helps so that they invest in usable technology R&D for improvements in current production, creating with the Prime, '*blurred technology'*.

6.4.5.3 Innovation and network performance

The Prime is learning, doing and thinking about technology for the future but it is aware that it needs to think about the future from the supply network perspective. There is clearly an opportunity to improve network performance by evolving the current supply network into one fit for the future. Trial and error is part of the collaboration process in the attempt to find the right mix of suppliers for supply network evolution.

6.4.5.4 Innovation and risk management

The prime is a technological leader but this is balanced by being very risk averse. It manages innovation and technology leadership by close monitoring and nurturing technologies that are developing well, for example, the application of composite materials. Many innovations are not adopted into products. The prime has invested in large scale production environments not used in the past, so is beginning to accept risk in this way.

6.4.5.5 Innovation and product services

Services are perceived as an area of opportunity rather than one of obligation. In the future, more business is expected to arise after the delivery of jetliners than it does today. There is an increasing awareness of product life-cycle particularly with reduced manufacturing and assembly at the Prime and the latent potential for services.

6.4.6 Enablers and constraints

Two underlying enablers are identified which are exploited and critical to the operation of the supply network: Information Communication Technologies (ICT) and Standards. Two constraints are also noted: own government restrictions on exports and lack of sufficient economic (and so industrial) development in low cost economies. Both constraints are acted upon by the Prime. The enablers and constraints are noted in Table 6-2.

Enabling:	**ICT:** Facilitating electronic collaboration around the clock **Standards:** Enabling integration of standard parts across the industry
Constraints	**Government Restrictions:** Barriers to selling in some countries created by withholding export licences **Industrial Development:** A lack of economic development, means that the Prime helps shaping and sometimes helps to build markets for the future, via government for infrastructure and industry for capabilities

Table 6-2 Enablers and Constraints relevant for the Prime

6.4.6.1 Enabler: Information Communication Technologies (ICT)

The adoption of technologies which enable engineers to collaborate across the globe is now embedded. This has been critical to facilitating global collaboration between the firm and its suppliers.

6.4.6.2 Enabler: Standards

The requirement for boiler-plate or standard product interfaces is essential. It enables suppliers to work to the same interface standards in the certainty that parts from different suppliers will be compatible. It also avoids the need for bespoke equipment and so keeps cost lower. Paradoxically, it is allowing a wider mix and match that is allowing customization to take place in a very agile manner.

6.4.6.3 Constraint: Government restrictions

Governments can hinder the export of commercial jetliners by requiring export licences, which have not been readily granted to some countries in the past. The prime would solicit leverage from potential new markets protecting the prime's market share from adverse effects.

6.4.6.4 Constraint: Industrial development

The prime takes a long-term view of markets and customers, developing relationships with industrial bodies in countries which are expected to buy jetliners in large numbers in the future. This can be market shaping activity if airspace is not yet open. These relationships cement the development of skills enabling firms in the customer nations to build infrastructure. Relationships have to be developed in the right way with the right individuals.

6.4.7 The prime and the survey

The survey instruments completed by respondents from the Prime only are analysed below, showing the significant inter-firm characteristics in their supply network. Three sets of results are shown (see Table 6-3): Scenario 1 (Table 1 first order), Scenario 2 (the equally weighted results from using the combined results of survey Table 1 and Table 2); and Scenario 3 (Table 2 pair-wise only). Figure 5-1 describes the three scenarios in more detail. The survey instrument is explained in more detail in Chapter 5 Section 4. There are 27 characteristics in total and the top 10 only are shown from each table. The top 10 are calculated using the coefficient of variation as described in chapter 5. The number to the left of the characteristic is the unique identifier of the characteristic, so for example, 23 is the identifier for lean practice in the supply network.

The top inter-firm characteristic across all three analyses is a culture of continuous improvement. The need for constant change is well understood in evolutionary thinking and is known as the Red Queen Effect. Based on a comment by the Queen of Hearts in Lewis Carroll's Through the Looking Glass: "*'A slow sort of country!'*

said the Queen. 'Now, HERE, you see, it takes all the running YOU can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!' (Carroll, 2008: ChII). The Red Queen effect has been adopted into evolutionary thinking as a principle that for an evolutionary system continuing development is needed just in order to "maintain its fitness" relative to the systems it is co-evolving with. (Van Valen, 1973) The principle has been further developed by others (Barnett and Hansen, 1996; Kauffman, 1995b).

The next three important inter-firm characteristics are investment in training, lean practice and can handle cultural differences. Investment in training and helping suppliers to improve their performance and competence is an important theme throughout the interviews. Reputation for quality is critical to the Prime and must be ensured through its relationships with suppliers as the suppliers are largely now independent. The ability to handle cultural differences is allied to investment in training because as the supply network becomes increasingly globalized investment in training needs to be responsive to different cultural needs. Cultural differences, relating to national cultures, are recognized in the interviews. Lean practice as a means of reducing waste and cost, is mentioned to a lesser extent in interviews. In fact, the notion of too much lean becoming an issue is highlighted.

FIRST ORDER		COMBINED		PAIRWISE	
12	culture of continuous improvement	25	investment in training	1	outsource competitive adv
5	long term relations	12	culture of continuous improvement	8	flexible operations
23	lean practice	23	lean practice	12	culture of continuous improvement
21	TQM procedures	13	can handle cultural differences	25	investment in training
25	investment in training	16	easy dialogue with supplier	13	can handle cultural differences
19	responsive to market change	8	flexible operations	22	just-in-time delivery
10	sharing knowledge	17	IT system integration	16	easy dialogue with supplier
7	subcontract whole systems	26	supplier development	23	lean practice
18	high levels of integration in chain	1	outsource competitive adv	19	responsive to market change
13	can handle cultural differences	21	TQM procedures	18	high levels of integration in chain

Table 6-3 Survey analysis Prime

6.4.8 Analysis of the prime

An analysis of the Prime in the context of the coevolution of the aerospace supply network should have something to contribute regarding four areas as defined in the Conceptual Framework (Chapter 4, Section 5). The first is the way in which the supply network archetype is perceived by the Prime. The second is the way in which integration occurs between the Prime and its suppliers. The third is the dynamics of the supply network. Last is the nature of coevolution between the Prime and the Supply Network.

6.4.8.1 Supply network structure

By selecting those core categories and sub-categories which refer to structural aspects of the supply network, six constructs emerge to describe the supply network of today: globalized, fewer product systems, consolidated, specialized, partnered and having fixed suppliers. The old vertically integrated archetype could be described as localized, many product parts, fragmented, diversified, owned and having replaceable suppliers. These are shown in Table 6-4.

Core category	Construct	Pole	Consequence
Globalization: Access to Skills	Globalized	Localized	Wide geographical dispersion of suppliers based on skills available
Globalization: Product Complexity	Fewer Product Systems	Many Product Parts	As product complexity is increased (could be supplier driven R&D innovation using new technologies), parts are bundled into product systems. New supply networks are created with fewer, and consolidated suppliers, who produce complex product systems; the Prime needs to manage fewer suppliers but each is of greater risk; Prime loses technological *build* knowledge to the supplier
Specialization: Consolidation	Consolidated	Fragmented	Few suppliers; network is less dense
Specialization: Diversification	Specialized	Diversified	1st tier supplying multiple customers belonging to multiple industries
Partnership: Vertical Disintegration	Partnered	Owned	Reduced control/power so collaboration needed; shared risk; supplier chooses own suppliers
Partnership: New Product Introduction	Fixed Suppliers	Suppliers not Fixed	Once implemented, the supply network is fixed, bar any supplier failures which are not prevented by the Prime

Table 6-4 Supply Network Archetype - Prime

6.4.8.2 Integration

If the supply network archetype describes the structure of the supply network, this sub-section attempts to describe how the methods of integration between the prime and its suppliers have changed. See Table 6-5. Integration from the Prime's perspective has characteristics more like the Constructs: global ICT infrastructure and system, global interface standards and ability to handle cultural differences.

Core Category	Construct	Pole	Consequence
ICT enabler	Global ICT infrastructure and systems	Traditional mainframe computing	Networks and computing power is distributed to anywhere in the world; systems can be accessed from any location
Standards enabler	Global interface standards	National standards	Interface protocols understood providing a shared language for producing integrated parts
Survey: Ability to Handle Cultural Differences	Ability to Handle Cultural Differences	Inability to Handle Cultural Differences	Cultural differences are understood, managed and acted upon with empathy

Table 6-5 Supply Network Integration – Prime

6.4.8.3 Coevolutionary dynamics of the prime and supply network

It has not been possible to separate dynamics from coevolutionary effects as the dynamics of mutual adaptation appear to result in new dynamics within feedback loops. The combined coevolutionary dynamics are possible to describe, i.e. the dynamics of inter-firm characteristics and their mutual adaptation with supply network structure.

Two coevolutionary dynamics appear to operate: one during the design of a new jetliner and one during the operation of the jetliner. The Prime and supply network coevolve as a result of a number of dynamics. The construct column of table 6-6 describes the coevolutionary dynamics of an operational supply network whilst the pole column describes those more akin to a supply network in inception. The operational supply network is characterised by large fluctuations in demand, responsiveness to multiple markets, increasingly value-added products, information translucency, investment in supplier training, and continuous improvement in innovation. Emerging supply networks are characterised by predicted demand, having an aerospace industry focus on manufacturing, creation of commodity products, information transparency, no supplier training and radical innovation.

6.4.8.4 Prime summary

This section concludes the case study of Prime, one of the largest aerospace manufacturing firms. The supply network structure from the perspective of the prime is one that is located across the globe, consolidated into few suppliers with specialized skills and knowledge, via a partnership arrangement. Integration occurs via information sharing, particularly using ICT, and by the use of global interface standards.

Core Category	Construct	Pole	Consequence
Specialization: Demand Fluctuation	Large demand fluctuation	Predicted demand	Having diversified suppliers increases the risk of delivery precision; supplier risk of failure is during the up-turn
Specialization: Demand Fluctuation	Multiple market responsiveness	Single industry focus	Supplier learns to meet the needs of other industries and brings that learning to the aerospace industry by way of innovations & improvements which can be adopted by the Prime.
Partnership: Quality Management	Value-added products	Commodity Products	Suppliers can learn from the Prime and increase quality standards, developing more value-add to products, increasing their likelihood of becoming selected for new supply networks.
Partnership: Information Sharing	Information translucency	Information Transparency	Prime to supplier information sharing translucency, risk of competitors gaining access.
Survey: Investment in Training	Investment in supplier training	No investment in supplier training	The prime invests resources in training of suppliers
Innovation: Manufacturing Processes	Continuous improvement	Stagnation	Improvements in production may be identified by either the Prime or the supplier, leading to continuous improvement
Innovation: R&D, Risk Management	Continuous improvement	Radical innovation	Once implemented, the jetliner (and the manufacturing process) is continuously improved, never radically innovated; Radical innovations are closely monitored
Survey: Culture of continuous improvement	Continuous improvement	Radical innovation	The survey top result for the Prime was a culture of continuous improvement

Table 6-6 Supply Network Coevolutionary Dynamics – Prime

The Prime and the supply network coevolve as a result of a number of dynamics: large fluctuations in demand, responsiveness to multiple markets, increasingly value-added products, information translucency, investment in supplier training, and continuous improvement in innovation and in quality outcomes. The nature of new supply networks is in contrast to operational supply networks. New supply networks involve radical product innovation often in collaboration with suppliers, using open information sharing.

The coevolutionary dynamics of the operational supply network cope with large demand fluctuations, often by selling to other industrial sectors. Continuous improvement in innovation by the supplier and investment in training by the prime, indicate a positive feedback loop. Whilst there is constant change, we note from the structure that first tier suppliers are rarely replaced in an operational supply network. New supply networks may introduce new suppliers, are likely to involve radical innovation and will be based on predicted demand. Product complexity is likely to have leapt forward from that within existing supply networks. More components are bundled into new systems, leading to specialization of suppliers in the supply network. This means that first tier suppliers are delivering design and integration work previously carried out by the Prime. The Prime is managing relationships nationally and internationally in order to compete globally and is moving away from design and manufacture.

The next section contains a case study of first tier supplier OEM(A).

6.5 Case Study OEM(A)

6.5.1 Introduction to OEM(A)

This case study concerns a 1st tier own-equipment manufacturer (OEM) with around £1,000m turnover and 10,000 employees. The firm is part of a publicly listed global technology company, who apply advanced technologies for security, medical, energy, and aerospace markets.

The next subsection presents a summary of the interview transcripts which describes facts and the shared views of interviewees. The semi-structured interview template used to collect interview data is shown in Appendix E.

6.5.2 Summary of OEM(A)

The outcome of a strategy of rapid growth by acquisition has led to a large number of OEM(A)'s businesses operating autonomously, with an increasing supplier base and duplication in products produced and sourced. Unlike its competitors who have seen massive lay-offs and re-structuring, OEM(A) has been sheltered due to its ability to win new business over the years. Profits are largely generated from replacement parts production for older aircraft allowing the largely zero-profit development of new solutions. But the cash cow is becoming leaner as competitors are manufacturing replacement parts at more competitive prices.

The driver for organizational change was an independent review of the industry (AIGT (Aerospace Innovation and Growth Team, DTI), 2003) which concluded that OEM(A) was a laggard compared to its competitors and that the stock market would find OEM(A)'s increasingly relatively poor performance unacceptable. Significant changes were required in areas of shared corporate goals, integration of information systems, use of lean production methods and supply chain management in order to reduce costs. OEM(A)'s vision of being a first tier supplier and leading global provider of innovative solutions required it to take a look at itself and leverage its potential across its businesses. A fundamental shift in strategy from allowing acquired businesses to continue operating without intervention, to a strategy of re-configuration and product alignment, had started when the case study was carried out. The new strategy was one of centralisation and rationalization, so that customers recognized OEM(A) as one business.

This was a major organizational change and a consolidation of supply chain services into a Supply Chain Organization. This new services organization was driving down costs in labour and parts by leverage through procurement and creation of preferred suppliers, whose margins would be protected and who would be fully integrated with OEM(A). The argument used was that competition is no longer between companies; it is supply chain against supply chain, and a loosely connected supply chain is no competition against a fully integrated one. A new Vice President with a track record was brought in to head the Supply Chain Organization.

Customer "*price-downs*" had led to the search for suppliers in low cost economies which are locations that OEM(A)'s competitors had already started to exploit. The focus of the Supply Chain Organization was not primarily on lean production as the nature of products in aerospace manufacturing is complex and the relatively lower volumes mean less cost reduction opportunities in commodity purchases. Significantly more potential is seen in strategic supply chain management and in the application of lean principles such as removing *muda* (non-value adding activities) in other functions such as administration.

The Supply Chain Organization is only two tier, with many Directors reporting to the Vice President. It is a virtual, centralised function permitting shared learning and driving standards and corporate strategy through OEM(A)'s businesses. Manufacturing is based largely in the UK and US, although low-cost economy manufacturing is on the horizon via the building of a manufacturing plant to be sourced with raw materials from the West.

OEM(A) is innovating based on customer's solutions and not by developing its own brand of products. This strategy is low risk for the firm insofar as it does not expend resources researching potentially unsellable products. However, the risk of being unable to deliver a conceptual customer requirement is potentially high although timescales are relatively long and new technologies abound.

Customer solutions are unique and are not replicated in new solutions for other customers, however, common components are re-used in other solutions and this is a good example of complex systems in use.

There are two structural outcomes led by two different groups of people in OEM(A) as shown in Figure 6-1. Change to the firm and the supply chain structure is driven by the OEM(A)'s Leaders based on pre-conceived, elsewhere evidenced formulas and manufacturing principles. Structural change to OEM(A)'s product portfolio is led by the elite core of engineers based on previous know-how, adequate time, and trial and error.

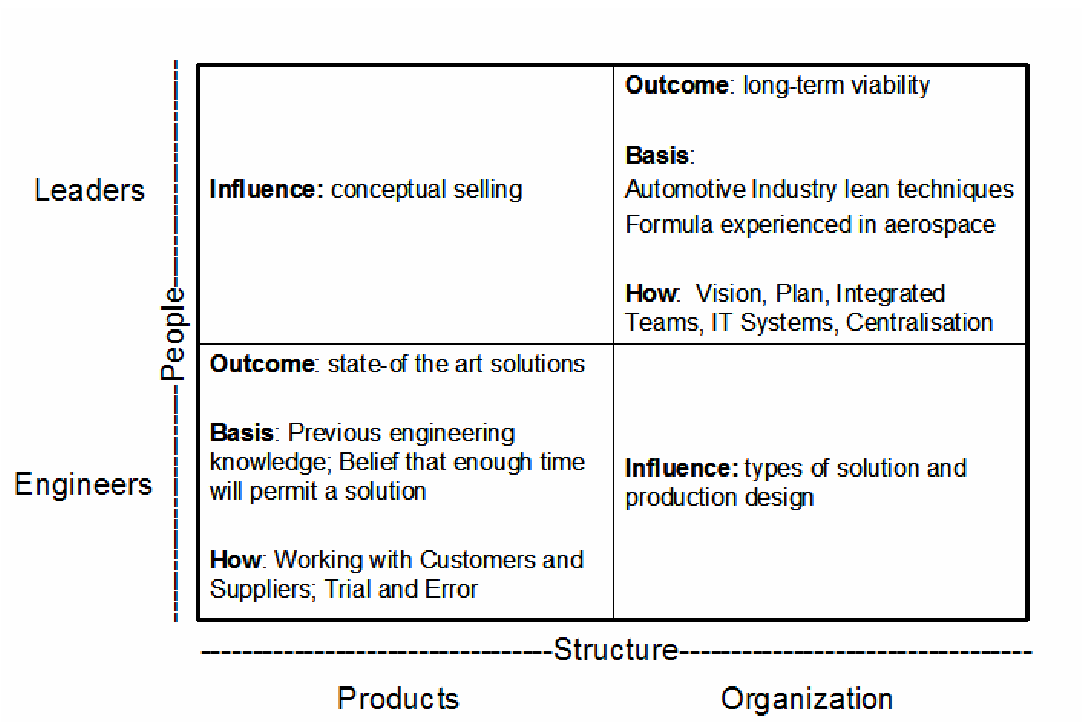


Figure 6-1 OEM(A) Influence of the Firm on Structural Outcomes

The requirement for products to have reduced costs without compromising quality or time-scale was stated. The outcome is being met by re-conceptualisation of the supply chain as an integration device (1) for operational exploitation using supplier contract management and (2) for exploration of solutions between customers, the Supply Chain Organization and preferred suppliers.

The development of preferred supplier relations (and indeed the recurring assessment of suppliers and their alignment to the OEM(A)'s technology road map) is taken for granted. It is assumed that suppliers want to be on the preferred list and are satisfied with protected margins and so it has been a surprise that some suppliers have not wanted this. There is a tension in the innovation of customer solutions which are structurally different from other current solutions. The requirements cannot be solved with today's technology and know-how, so Engineers have to create something novel by using different resources or techniques, or combining in different ways, in order to deliver a solution that is state of the art. There is no attempt to proceduralize this process (or perhaps art), but it has been considered, since it is recognised that some of what the Engineers do is actually quite "*routine*".

6.5.3 Results for OEM(A)

The coding of interview transcripts identified four core categories:

- Globalization
- Firm Reorganization
- Improvement
- Innovation

Globalization for OEM(A) is concerned with both sourcing low cost products and with access to global markets. Firm Reorganization refers to the creation of the Supply Chain Organization and the rationalization of suppliers, but also rationalization of the Businesses to avoid the duplication of products. Improvement with suppliers encompasses quality management, creating joined-up solutions, and information sharing. The last core category is Innovation which is evident in the design of engineering systems and which is being threatened by competition. These are shown in more detail in Table 6-7. One type of enabler was identified: Standards.

Core Category	Sub Category
Globalization: the availability of low cost products and access to global markets	**Low Cost:** Access and availability of low cost products **Competition:** Access to global markets required to maintain status as 1st tier supplier to the Primes
Firm Reorganization: Changes within the firm and its businesses so that the firm acts strategically	**Centralized Supply Chain Organization:** Rationalization of supply chain activities into a central service **Product Rationalization:** Deciding which businesses would produce which products
Improvement: working with higher-quality suppliers in a more integrated way for improvement	**Quality Management:** Maintaining and improvement of quality standards is critical and drives supplier selection **Joined-up solutions:** Closer working with suppliers to deliver products in an integrated way **Information Sharing:** Mutual sharing of information but not everything
Innovation: customer-led innovation	**Engineering designs:** Engineering innovation for customer-led product solutions **Maintenance and repair:** Competition from cheaper suppliers threaten cash flow

Table 6-7 Core Categories in the Supply Network perceived by the OEM(A)

6.5.4 Analysis of OEM(A)

In a similar way to the analysis of the Prime, four aspects of firm and supply network coevolution are examined. The first is the supply network archetype as perceived by OEM(A). The second is the way in which integration occurs between OEM(A) and its suppliers. The third and fourth are merged to describe the coevolutionary dynamics between OEM(A) and the supply network.

6.5.4.1 Supply network structure

By selecting those core categories and sub categories in Table 6-7 which refer to structural aspects of the supply network, three constructs emerge to describe the supply network archetype of today: globalized, consolidated, and disintermediated. The old archetype could be described as localized, fragmented, and supplied. These are shown in Table 6-8.

Core category	Construct	Pole	Consequence
Globalization: Low Cost	Globalized	Localized	Growth in use of low-cost economies
Firm Reorganization: Centralized Supply Chain Organization	Consolidated	Fragmented	Fewer suppliers; network is less dense
Innovation: Maintenance and Repair	Disintermediated	Supplied	Suppliers and other firms providing services for OEM(A)'s products

Table 6-8 Supply Network Archetype - OEM(A)

6.5.4.2 Integration of supply network

This sub-section describes how the integration between the prime and its suppliers has changed.

Integration from the OEM's perspective now has characteristics more like the Constructs: Standards that can be used for multiple customers, global component standards and integrated designs as shown in Table 6-9. Integration has moved away from bespoke single customer solutions, local standards and bi-lateral designs.

Core Category	Construct	Pole	Consequence
Globalization: Competition	Standards for multiple customers	Single customer solutions	OEM(A) adopts standards that enable components to be used in multiple product solutions for various customers
Standards enabler	Global component standards	Local standards	Common standards used permitting the same components to be used in product solutions for various customers.
Improvement: Joined-up solutions	Integrated designs	Bi-lateral designs	Customer, OEM(A) and supplier, three way integrated designs and solutions

Table 6-9 Supply Network Integration - OEM(A)

6.5.4.3 Coevolutionary dynamics of OEM(A) and the supply network

The coevolutionary dynamics of the supply network from the perspective of the OEM are shown in Table 6-10. The coevolution of the firm and the supply network is demonstrated by activity both upstream and downstream.

Core Category	Construct	Pole	Consequence
Improvement: Quality Management	Supplier improvement	Supplier Stagnation	Preferred supplier standards continuously improving
Innovation: Engineering designs	Design Stagnation	Radical Innovation	Once implemented, the product design is not updated; radical innovation occurs for new products in new supply chains
Firm Reorganization: Centralized Supply Chain Organization	Consistent quality	Inconsistent quality	Reputation of OEM(A) is maintained by sourcing goods from fewer preferred suppliers providing consistently high quality goods. Supply network consolidation as other suppliers may be acquired or go under
Improvement: Information Sharing	Information Sharing	Information Withholding	Mutual sharing of information, better warning of fluctuations in demand

Table 6-10 Supply Network Coevolutionary Dynamics - OEM(A)

The new supply network dynamic has the characteristics of the Construct column – supplier improvement, design stagnation, more consistent quality and information sharing. Earlier versions of the supply network were more like the construct pole column, which were less well performing.

The coevolution of the supply network hinges on fewer suppliers and more (global) customers. The firm learns from both its higher quality suppliers and its wider customer base.

6.5.4.4 OEM(A) summary

This section concludes the analysis of OEM(A). The supply network structure perceived by this 1st tier supplier is one that is globalized and in which its suppliers have consolidated as a result of needing to compete for all the OEM's business. The

OEM is also aware that its products are now being maintained and repaired by its suppliers and so the OEM is losing out on this business. Integration in the supply network is achieved by the use of global interface standards, the use of standard components to create multiple customized solutions and integrated designs. There is on-going supplier improvement in the operational supply network, but largely design stagnation for existing products. The firm coevolves with the supply network by learning from its fewer higher quality suppliers and from its wider global customer base. The supply network coevolves with the systems that the OEM is able to source and deliver.

The next section contains a case study of another 1st tier OEM in the aerospace industry.

6.6 Case study OEM(B)

This firm is part of a much larger group, which is present in financial services, energy and technology infrastructure and appliances and media markets. The integrated systems firm OEM(B) is a relatively new acquisition but complementary to the group's other aerospace activity.

6.6.1 OEM(B) Results

This case study is constructed using open-ended interviews and repertory grid technique interviews. The coding of interview transcripts identified three core categories:

- Prime Dominance
- Revolution
- Globalization

One type of enabler and one type of constraint were also found. The enabler is the use of automation and robotics to replace labour. The constraint is the difficulties in adopting Western quality standards in low cost economies.

Each of the three core categories are broken down into sub categories as shown in Table 6-11 and described in detail in the following sub-sections. The relevant source interview transcripts are shown in Appendix M.

The next sub-sections describe the core categories and sub-categories which emerged from the open-ended interviews.

Core Category	Sub Category
Prime dominance: the influence of primes on the 1st tier firm and its suppliers	**Risk-sharing:** Customer (Prime) becoming part of firm, behaviours rippling through to suppliers **Supply chain effects**: 2nd tier supplier reduction **Future is Services:** Power by the hour
Revolution: the step change in the firm to meet the new demands from the primes	**Systematization**: Reorganization of jetliner components into integrated systems, each of which a 1st tier can manage **Firm Growth:** Planned to double firm size in three years **2nd Tier Challenges:** Local suppliers rising to the challenge
Globalization: the exploitation of labour skills in low cost economies	**Competitive Advantage:** Manufacturing in LCE as a strategy to reduce cost **Classifying LCEs:** Classifying regions and managing them according to the classification **Future In-Country Builds:** Drivers for LCE production

Table 6-11 Core Categories in the Supply Network perceived by the OEM(B)

6.6.2 Prime dominance

The influence of the primes on the 1st tier firm and its suppliers has been effected by the implementation of risk-sharing partnerships. These partnerships are implemented via programmes and related contracts which enable the Primes to be explicit about what must be done to supply a product, including the activities that must be achieved by the 1st tier firm's suppliers.

6.6.2.1 Risk sharing

Whilst the primes enforce their dominance in different ways, they both have "templates" or "formats" to achieve defined outcomes. This dominance appears the major way for a prime to mitigate risk for mutual benefit with OEM(B). The firm, not the prime, holds intellectual property rights (IPR) to the systems they develop. If OEM(B)'s systems cause a jetliner to perform inadequately or in the worst case to fail with fatal consequences, then it is OEM(B) who owns the consequences of the failure. Because this failure can have such devastating consequences for the prime, it is not surprising that the prime, who would have in the past designed and produced these parts, remains very close to its 1st tier suppliers, and via them to its 2nd tier suppliers.

6.6.2.2 Supply chain effects

Two types of 2nd tier supplier are described. The first is the larger supplier with whom technology partnerships are implemented. The second are commodity providers with whom tactical relationships exist for the provision of machined items. The polarization of suppliers into these two categories has enabled a more strategic approach to decision making in respect of outsourcing. The primes are particularly interested in the main 2nd tier partners and in reducing the numbers of supply chain members. In terms of implementing supply chain solutions, cross-functional teams from the firm are put together for collaborative working with the prime and relevant suppliers.

6.6.2.3 Future is services

The main profit for OEM(B) is in the after market, as manufacturing is not profitable. Apparently driven by airlines, the notion of paying for each flight hour, means that the future is not in jetliner sales. On the contrary it would be to engineer systems and components to be long-lived and return greater profitability. This implies huge responsibilities and inter-dependencies on the other systems of the jetliner. The enormity of the task of carving up flight hour charges between the systems providers would require great collaboration, consensus and trust.

6.6.3 Revolution

A revolution in aerospace manufacture is underway, driven by the systematization of jetliner design, with massive changes to the 1st tier and having a ripple effect into the 2nd tier and low-cost economy manufacture.

6.6.3.1 Systematization

The systematization of the jetliner and the consolidation of 1st tier suppliers have resulted in some 1st tier suppliers taking on whole systems and acting as systems integrators. Suppliers who were previously 1st tier are now working for 1st tier systems' integrators, like OEM(B), to produce integrated systems. And integration work previously carried out by the prime has moved to the 1st tier. The role of systems integrator is seen as a competitive position of engineering and integration expertise. Suppliers further down the chain will become increasingly commoditized and will have to compete on price.

6.6.3.2 Firm growth

In order to deliver the demands and expectations of the primes, the firm has a growth plan to double in size over 3 years and to outsource at least commodity production to the Far East.

6.6.3.3 2nd tier challenges

OEM(B) is taking on more higher value work and needs its suppliers to rise to the challenges of moving up with them. There are no plans for vertical integration and the trend is to buy more, particularly high volume commodity products from low cost economies, and to make less. Local suppliers will need to take on component design and manufacturing of low volume higher value work. Selection of these suppliers will be based on their change orientation and continuous innovation approach, especially in designing for manufacture. Numbers of suppliers are likely to reduce as there will need to be consolidation to attract good engineers.

6.6.4 Globalization

Whilst the phenomena of globalization for the Prime enables access to skills and markets, globalization for OEM(B) is perceived as a strategy for cost reduction. The strategy is targeted at high-volume, low value-add manufacturing for now, although LCE regions are being classified already based on anticipated future needs. Demands by LCE countries to manufacture components for jetliners which they themselves will buy, is likely to establish these firms as future jetliner producers.

6.6.4.1 Competitive advantage

Quality is mandated and whilst delivery is very important in order to reduce the time to put new products into production, it is cost which is driving competitive advantage.

Future jetliner pricing is reducing so much that it is already near to the cost of the raw materials, before any processing. It is driving the use of low-cost economies as western firms simply can't compete on manufacturing cost of high-volume commodity parts. Assembly is likely to shift to LCEs leaving only engineering and support functions in the West.

6.6.4.2 Classifying LCEs

Transition activity is in place, whereby skills are being developed in LCEs. A Far Eastern country is divided into regions, and a team is in place in each region. Whilst managers are currently expatriates, they will be replaced by local people within 2 years. Local capabilities are being increased and they will be the ones to contribute to higher-value manufacturing in the future.

6.6.4.3 Future in-country builds

It is expected that Primes will mandate "a level of in-country content" in their contracts with OEM(B) because the Primes themselves will be selling most jetliners into these LCE countries. Whilst these contracts will relate only for jetliners destined for the same country, it is likely that next generation jetliners will use the same manufacturing and assembly plants.

6.6.5 Enablers and constraints

A potential alternative to the use of cheap labour in low cost economies is investment in technology for automation of production. This is perceived in some cases to be an enabler when the set up costs for overseas labour prohibits its use. A constraint is the difficulty in adoption of the required approaches to quality management which require the intervention of OEM(B). The enablers and constraints are noted in Table 6-12.

Enabling:	**Automation:** Replacing labour with technology as an alternative to outsourcing to LCEs
Constraining	**Quality:** Western quality systems are not easily adopted in LCEs

Table 6-12 Enablers and Constraints relevant for OEM(B)

6.6.5.1 Automation

The use of technology to automate production with minimum manual oversight means that outsourcing to LCEs generates minimal labour cost savings, particularly when set-up costs can be large. Automation may not be possible everywhere, for example final assembly. If final assembly moves to LCEs then it makes sense logistically to have parts supply near final assembly.

6.6.5.2 Quality

Suppliers in LCEs still need direction in western quality systems and approaches in order to carry out manufacture to the necessary standards. As machining capability increases, other quality standards are required for more complex work and to make more cost savings. These still need to be influenced by the West.

6.6.6 Repertory grid interviews OEM(B)

Four repertory grid interviews were completed at OEM(B) which are presented below. Note that Supp1, Supp2 etc refer to different suppliers on each grid.

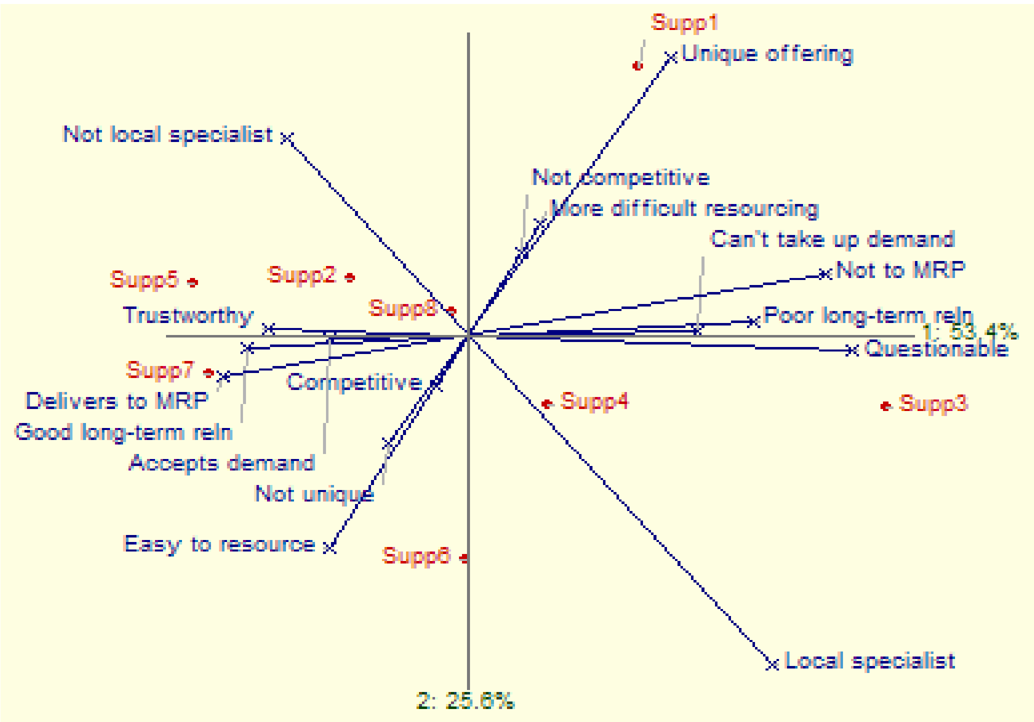


Figure 6-2 OEM(B) Repertory Grid 1

Factor 1 explains over 53% of the variance for Repertory Grid 1 in Figure 6-2. Factor one divides those suppliers who are commodity suppliers, have a good long-term relationship, with good delivery performance, trustworthiness and competitive pricing from those who are not. A good long term relationship was ranked the highest priority, and ability to meet MRP (delivery capability) was ranked second. The construct Local specialist is likely to provide a differentiator as can be seen from its cross-cutting nature in Figure 6-2.

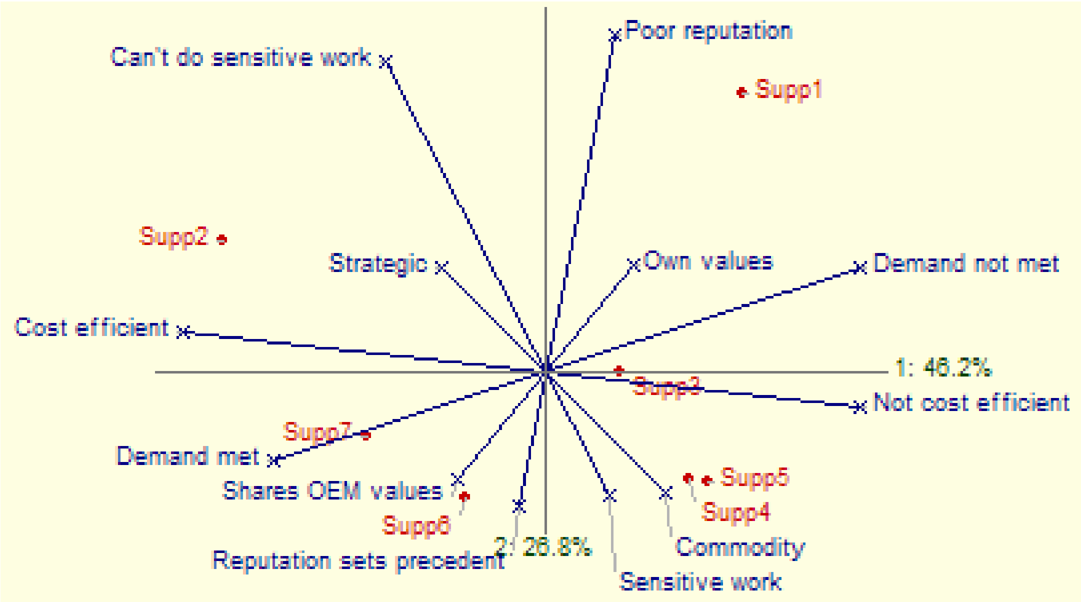


Figure 6-3 OEM(B) Repertory Grid 2

Factor 1 explains over 46% of the variance and factor 2 explains nearly 27% in Figure 6-3. This grid is more dispersed than Grid 1 and so is less explanatory. Suppliers who are cost efficient and able to take up demand capacity requirements are described by factor 1. Suppliers who share OEM(B)'s values, who have a good reputation, are able to undertake sensitive work and who produce commodities are similar along factor 2. Strategic suppliers were ranked the highest priority followed by cost efficient suppliers.

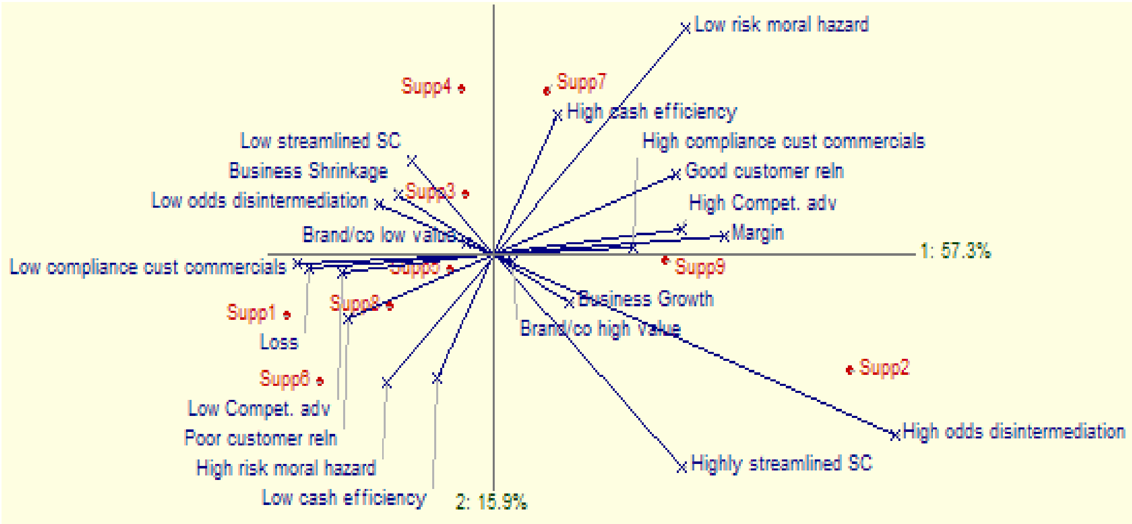


Figure 6-4 OEM(B) Repertory Grid 3

Factor 1 explains over 57% of the variance and factor 2 around 16% in Figure 6-4. High compliance with customer commercial requirements, good customer relationship, high competitive advantage in the market place, OEM(B) able to make a margin, business growth and high company/brand value are explained by factor 1, even though only 1 supplier is 'like' this – Supp9. High chances of disintermediation (the supplier providing products and/or services directly to the OEM's customer) is an interesting construct as it has the greatest variance (3.1) of this data set. A highly streamlined supply chain also appears as an interesting construct, with only Supp2 having this desirable characteristic.

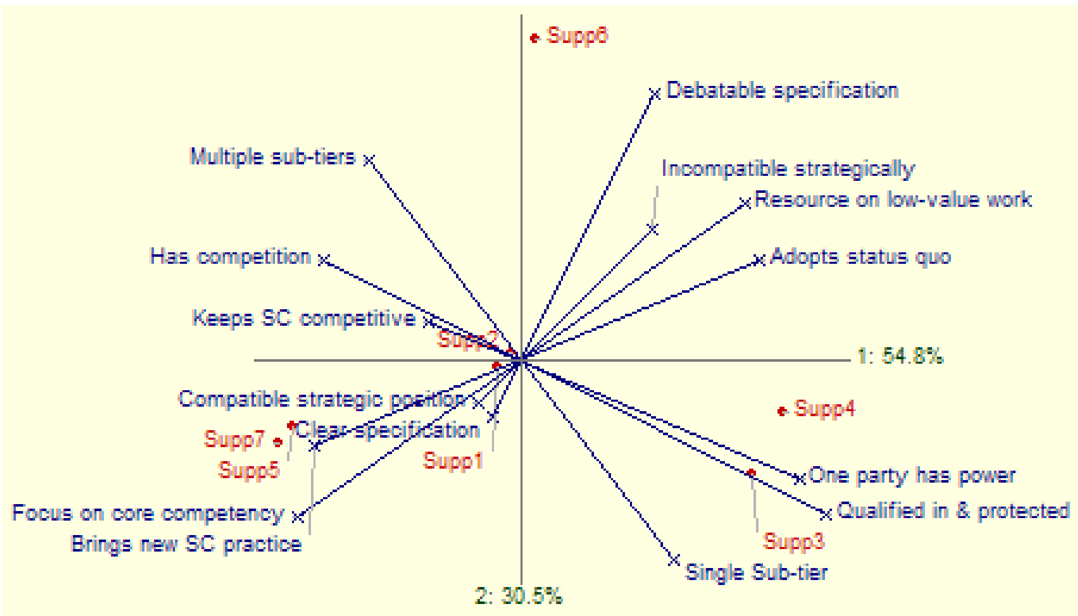


Figure 6-5 OEM(B) Repertory Grid 4

Some 55% is explained by Factor 1 and a further 30% by factor 2 shown in Figure 6-5, so this is the most explanatory repertory grid, as two underlying factors are clearly exposed. Suppliers who have competition, who have to keep the supply chain competitive, who focus on their core competency and bring new thinking into SC practice are preferred traits explained by factor 1. Factor 2 explains supplier who have multiple sub-tiers, who debate specifications and are incompatible strategically. For this respondent at OEM(B) the top priority is for the supplier to be open to competition and for there to exist a natural tension in the supply chain. Open to competition is the construct with the most variance which indicates that suppliers are or are not like this, i.e. it is more like a binary status.

6.6.7 OEM(B) and the survey

The survey instruments completed by respondents from firm OEM(B) are analysed showing the significant inter-firm characteristics in their supply network. Three sets of results are shown (see Table 6-13): those from survey Table 1 (first order), those from survey Table 2 (pair-wise) and the equally weighted results from using both survey Table 1 and Table 2 (combined). The survey instrument is explained in more detail in Chapter 5 Section 4.

FIRST ORDER		COMBINED		PAIRWISE	
5	long term relations	27	monitoring supplier	27	monitoring supplier
16	easy dialogue with supplier	10	sharing knowledge	25	investment in training
6	formal partnership	12	culture of continuous improvement	12	culture of continuous improvement
25	investment in training	25	investment in training	8	flexible operations
9	risk-sharing	8	flexible operations	10	sharing knowledge
10	sharing knowledge	15	high level of planning and control	19	responsive to market change
23	lean practice	3	high level collaboration	5	long term relations
13	can handle cultural differences	19	responsive to market change	23	lean practice
12	culture of continuous improvement	6	formal partnership	26	supplier development
15	high level of planning and control	5	long term relations	3	high level collaboration

Table 6-13 Survey analysis OEM(B)

The top inter-firm characteristic across all three analyses is investment in training. This indicates the importance of raising supplier performance. The next two important inter-firm characteristics are sharing knowledge and a culture of continuous improvement.

These inter-firm characteristics are evident in both types of interviews, reflecting the increasing need to collaborate, raise standards and develop new skills.

6.6.8 Analysis of OEM(B)

OEM(B) is analysed in this section in the same way as the Prime and OEM(A).

6.6.8.1 Supply network structure

By selecting those core categories and sub categories which refer to structural aspects of the supply network and using the results of the repertory grid interviews and survey data, four key constructs emerge to describe the supply network of today: systematized, consolidated 1st and 2nd tier firms, globalized and good long-term relationships.

Core category	Construct	Pole	Consequence
Revolution: Systematization	Systematized	Component-sourced	1st tier delivering integrated systems, simplifying increasing complex components and supply chain relationships
Revolution: Firm Growth	Consolidated 1st Tier	Fragmented 1st Tier	Growth in the size of 1st tier firms but a reduction in the number of them
Prime Dominance: Supply Chain Effects	Consolidated 2nd tier	Fragmented 2nd tier	2nd tier suppliers consolidating in order to meet increased demands of OEM(B)
Globalization: Competitive Advantage	Globalized	Localized	Transfer of manufacturing to LCEs
Globalization: Future In-Country Builds	Buyer influence on manufacture sourcing	National influence on manufacture sourcing	Buyer power increasing, so that future airline owning nations can insist on own country as source of manufacture, rather than the use of Prime home nation suppliers
Rep Grid 1: Factor 1	Good long-term relationship	Poor long-term relationship	Trust and delivery performance are to be expected from a good long-term relationship

Table 6-14 Supply Network Archetype - OEM(B)

Influence from LCE nations for local manufacture sourcing will shift the manufacturing base over the next 15 years to LCE nations. The old archetype could be described as component-sourced, fragmented 1st and 2nd tier suppliers, localized, poor long-term relationships, and national influence on manufacture sourcing. These are shown in Table 6-14.

6.6.8.2 Integration of the supply network

This sub-section describes how the integration between OEM(B) and its suppliers has changed.

Core Category	Construct	Pole	Consequence
Rep Grid 3: Factor 1	High Customer Empathy	Low Customer Empathy	Suppliers who understand OEM(B)'s customer specifications and have a good relationship with the Prime, are preferred
Quality Constraint	Western quality standards	Eastern quality concerns	Western quality systems are not easily adopted in LCEs

Table 6-15 Supply Network Integration - OEM(B)

Integration from the OEM's perspective has the characteristics of the Constructs column. Integration is achieved by some 2nd tier suppliers having a high empathy with the Prime with the support of 2nd tier suppliers to adopt Western quality standards in order to deliver increased supply network performance. These are shown in Table 6-15.

6.6.8.3 Coevolutionary dynamics of OEM(B) and the supply network

The preferred coevolutionary dynamic between OEM(B) and the supply network is described by the Constructs column in Table 6-16. They include moving towards selling services, distant monitoring by the Prime, rising 2nd tier capabilities, technology automation, cost efficiencies, competitive suppliers, continuous improvement and sharing knowledge. For the future, new business models will be required throughout the supply network as it moves away from the current dynamic of maintenance and repair profits towards providing services (flight) by the hour thereby taking a long-term focus.

The coevolution of the supply network is currently influenced by the strategic advantage obtained from low-cost labour; however technology automation is an alternative route. Closer monitoring by the Prime is likely if the second tier supplier is not performing. Withholding knowledge from the supplier if they are less trusted results is a negative feedback loop, preventing performance improvement.

Core Category	Construct	Pole	Consequence
Prime Dominance: Future is Services	Services sold	Products sold	Flight hours are sold, requiring new business models throughout the supply chain and moving away from maintenance and repair cash cow.
Prime Dominance: Risk-Sharing	Distant monitoring by Customer (Prime)	Close monitoring by Customer (Prime)	Behaviours required by the Prime rippling through OEM(B) to suppliers
Revolution: 2nd Tier Challenges	Rising 2nd tier capabilities	Falling 2nd tier capabilities	2nd tier who are able to take on more of the 1st tier's work will develop new capabilities needed for future production
Globalization: Classifying LCEs	Growing 2nd tier capabilities	Stagnating 2nd tier capabilities	Proactive development of suppliers based by their classification
Automation Enabler	Technology automation	Low-cost Labour	Replacing labour with technology an alternative to outsourcing to LCEs
Rep Grid 2: Cost Efficiency	Cost Efficient	Not Cost Efficient	Suppliers who are cost efficient are preferred
Rep Grid 4: Factor 1	Competitive Suppliers	Suppliers holding power	Competitive supplier bring lower costs and innovation to the supply chain
Survey: Culture of Continuous Improvement	Continuous Supplier Improvement	No Supplier Improvement	Continuous Improvement delivers higher supply chain performance
Survey: Sharing knowledge	Sharing knowledge	Withholding knowledge	Sharing knowledge with suppliers delivers better supply network performance

Table 6-16 Supply Network Coevolutionary Dynamics - OEM(B)

6.6.9 OEM(B) summary

This section concludes the analysis of OEM(B). OEM(B) perceives the supply network structure as one that is systematized, has consolidated many 2nd tier suppliers and has good long-term relationships. It is becoming increasingly globalized. OEM(B) recognizes consolidation in the market place and the reduction in numbers of

1st tier suppliers. Influence from LCE nations for local manufacture sourcing will shift the manufacturing base over the next 15 years to LCE nations.

Integration in the supply network acts is enabled by the use of Western quality standards, and empathy between 2nd tier suppliers and the Prime's products.

Two dynamics operate in the supply network. Some 2nd tier suppliers are perceived to continuously improve, have growing capabilities, are open to competition, share knowledge and achieve cost efficiencies. They are not highly monitored by the primes. Strategic advantage is obtained from low-cost labour. This will change over time to providing a strategic advantage in design engineering skills as capabilities in LCEs rise and they are able to take on more high-value work. As LCEs are able to influence local manufacture for products which they will buy for themselves, they are likely to become the new base for aerospace manufacturing. OEM(B) will move up the value chain specializing in its own systems.

The second dynamic occurs where 2nd tier suppliers hold the power in their relationship with OEM(B) and so are not cost-efficient. These suppliers appear not to improve, capabilities stagnate and close monitoring by the Prime is likely. Withholding knowledge acts negatively for performance and the relationship.

For the future, new business models will be required throughout the supply chain as it moves away from the current dynamic of maintenance and repair profits towards providing services (flight) by the hour thereby taking a long-term focus.

This is the end of the case study on firm OEM(B), a large systems integrator in aerospace manufacturing. The next section contains a case study of a 2nd tier supplier to the aerospace industry.

6.7 2nd Tier Firm

6.7.1 Introduction to SecondT

SecondT is a UK manufacturer of valued-added components to multi-national aerospace and non-aerospace customers. It is a fast growing firm increasingly supplying parts to the aerospace industry and perceives 90% of its future revenue from manufacturing of box-builds/electronic assemblies for aerospace firms.

SecondT expects the aerospace industry to move in the same way as automotive; there will be more box builds/electronic assemblies reflecting increased integration of components. In 3 years time SecondT expects to increase its market share in value-added work in niche markets; Far Eastern countries do some of this now but in small volumes. It is innovating in process technologies which it perceives as a way to be differentiated between other second tier suppliers. The expectation is for 35% of low-added value manufacturing to be outsourced and no increase in labour at SecondT.

6.7.2 Results for SecondT

Component bundling reduces the number of suppliers to the OEM and creates the 'systems integrator' beneath the airframe prime. Bundling may be essential as the airframe prime may not be able to cope with the increasing components of the aircraft. Process technologies become a focus for SecondT as they provide a competitive edge. Process IPR is less of an issue for the systems integrator than product IPR.

When customers request orders early or increase demand, SecondT needs to exploit manufacturing capacity. Machine tools may buckle under the load, people doing overtime cost more and people with adequate skills cannot be easily contracted. Transport costs increase due to urgent delivery needs versus planned deliveries. Costs are not passed onto the customer so profit is reduced although revenue increases.

This is a negative feedback loop resulting in lower overall profits. Alternative routes to supply the customer are required or customer business is lost.

The use of low-cost economies is growing however cultural attitudes to western goods create opportunities for profiteering. *"But it {Far Eastern Countries deleted} is such a corrupt society and fraudulent components end up on the PCB. For example, Person A owns a manufacturing company and sits on the board of {Far Eastern Countries deleted} companies. Lorry drivers freight the components from {Far Eastern Country deleted} to {Far Eastern location deleted}. The lorry driver stops on the way and opens the goods, takes out the good components and puts fraudulent parts in. The pallet may contain 2 million components with a market value of $5 each. When the components go into the distribution network and start failing (takes only a few weeks for this to come out), there is then a shortage of getting hold of good product. The manufacturer knows then that the components are fraudulent but the supplier has already been paid. The market value of the components then rises to $25-$30 per component. Aerospace then charges more to the consumer. Can't stop manufacturing, and have to buy the high-priced good components."*

Organizational innovations in particular affect the agility, cost and delivery capacity of the firm. Adoption of Just-in-time and 'kanban' methods reduce stock holding levels and so reduce costs but increase risks if the supply network cannot deliver within timescales. These methods develop agility skills in suppliers, or it can bankrupt them. Fewer suppliers mean that costs may rise to the systems integrator as the number of suppliers able to deliver is reduced. Agility requirements are pushed up the supply chain and increases raw materials holdings for end of chain suppliers. In-house manufacturing policies eliminate 'MUDA', reducing waste and so cuts costs.

Performance metrics are weighted differently depending on the type of manufacturer. Flexibility and document accuracy are included but account for only 5% of evaluation. For the Distributor, on-time delivery is most important; for suppliers manufacturing aerospace products, it is quality not cost that matters. For PCB manufacturers, there is equal weighting between delivery, quality and cost performance. These are shown in Table 6-17.

	On Time Delivery	Quality	Cost	Flexibility	Document Accuracy
Distributor	60%	5%	30%	3%	2%
PCB manufacturer	30%	35%	35%	3%	2%
Aerospace manufacturer	20%	70%	5%	3%	2%

Table 6-17 Performance Metrics for SecondT suppliers

6.7.3 Repertory grid interviews SecondT

Graphical results for Repertory Grid interviews were obtained using *RepGrid*, a freely available software program for the analysis of repertory grids. Two repertory grids were completed; the first finding the constructs relating to customers (Figure 6-6), the second finding constructs relating to suppliers (see Figure 6-7). For each repertory grid, the two principal components are found and using multivariate techniques, the locations of the elements and constructs (both poles) are plotted. Chapter 5 Sub-section 3.6 contains more information about Repertory Grid analysis, validity, limitations and so on.

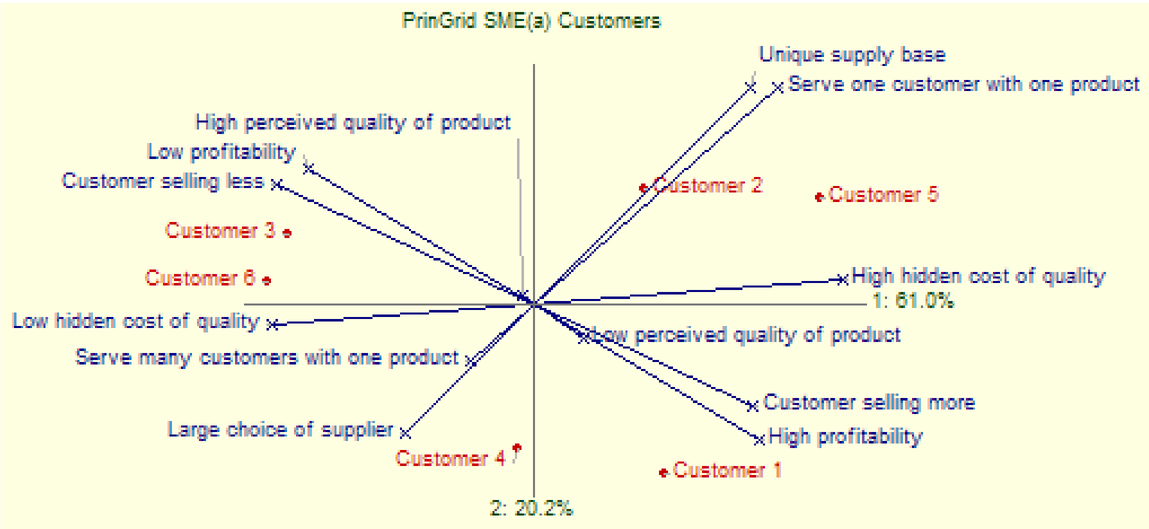


Figure 6-6 Factors relating to Customers - SecondT

Factor 1 in Figure 6-6 explains 61% of the variance and factor 2, 20%. Based on factor 1, we find that highly profitable customers are those with an increasing share of their markets, have a unique supply base and product base but have a high hidden cost of quality to the supplier (SecondT).

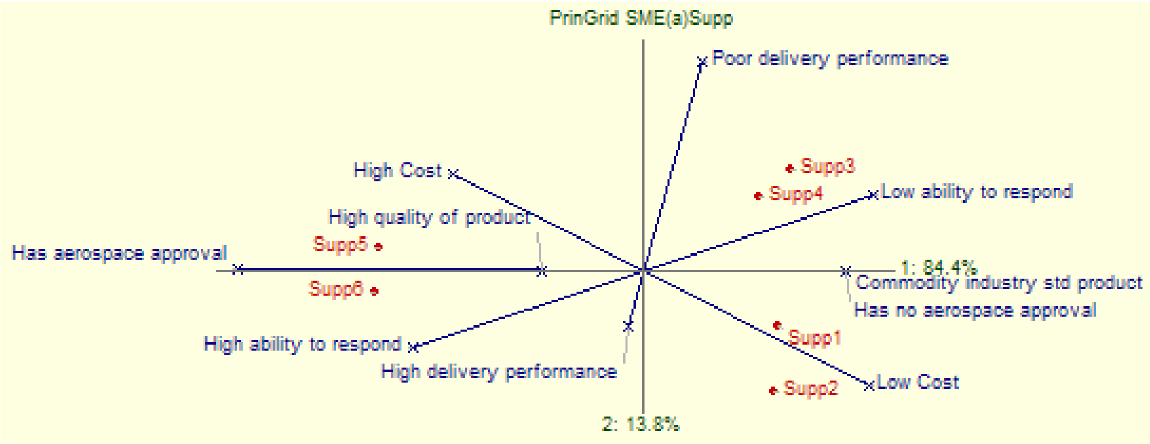


Figure 6-7 Factors relating to Suppliers - SecondT

Factor 1 in Figure 6-7 explains some 84.4% of the variance and largely differentiates between commodity product suppliers who are low cost, do not have aerospace approval and have low ability to respond (lack of inventory), and suppliers who are high cost, high quality, high delivery performance suppliers, with aerospace approval.

6.7.4 SecondT results

Semi-structured and Repertory Grid interviews identify the core categories and sub-categories shown in Table 6-18. Four core categories are found: Globalization, Supplier Relationship, Customer Relationship, and Innovation. Globalization is driven by low cost opportunities. Certification and delivery performance are aspects of supplier relationship which are critical. Product complexity and the increasing visibility of hidden costs are aspects of customer relationship. The focus of Innovation is on process technology enabling SecondT to create competitive edge for its products.

Core Category	Sub Category
Globalization: the use of low cost economies to manufacture components	**Low Cost:** Access and availability of low cost products but can be difficult to overcome corruption
Supplier relationship: varies with type of supplier, commodity suppliers improving delivery performance	**Certification**: certificated aerospace manufacturers limited in numbers, very high performance and very high cost **Delivery Performance:** Improved delivery and inventory management, becoming responsive to demand fluctuations
Customer relationship: standardized components used for many customers to create unique solutions; demand fluctuations eroding profitability	**Product Complexity:** More box-builds and electronic assemblies as components become more integrated **Hidden costs of demand fluctuations**: delayed or increased demand creating costs which are not recovered
Innovation: process innovation as the manufacture of value-added products is increased	**Process Technology:** Focusing on production process technologies to create a competitive edge

Table 6-18 Core Categories in the Supply Network perceived by the SecondT

6.7.5 SecondT and the survey

The survey instruments completed by respondents from SecondT are analysed in Table 6-19, showing the significant inter-firm characteristics in their supply network. Three sets of results are shown as before. There is more disparity between first order and pair-wise results than for the other firms, however, two inter-firm characteristics are agreed upon: Easy Dialogue with Supplier, and Lean Practice. The pair-wise results suggests that there is more control and planning, dominance and monitoring of suppliers than first order results suggest, as these focus on collaboration and long-term relations.

FIRST ORDER		COMBINED		PAIRWISE	
3	high level collaboration	19	responsive to market change	15	high level of planning and control
21	TQM procedures	3	high level collaboration	16	easy dialogue with supplier
23	lean practice	18	high levels of integration in chain	14	high level of dominance over supplie
16	easy dialogue with supplier	7	subcontract whole systems	23	lean practice
5	long term relations	16	easy dialogue with supplier	27	monitoring supplier
26	supplier development	10	sharing knowledge	12	culture of continuous improvement
10	sharing knowledge	23	lean practice	22	just-in-time delivery
24	explorative learning practices	12	culture of continuous improvement	26	supplier development
6	formal partnership	5	long term relations	6	formal partnership
9	risk-sharing	22	just-in-time delivery	19	responsive to market change

Table 6-19 Survey Analysis SecondT

6.7.6 Analysis of SecondT

In a similar way to the analysis of the other firms in this case study, four aspects of firm and supply network coevolution are examined. The first is the supply network archetype, the second is integration with suppliers, third is the dynamics of the supply network and last is the nature of coevolution.

6.7.6.1 Supply network structure

By selecting those core categories and sub categories which refer to structural aspects of the supply network, two constructs emerge to describe the supply network of today: globalized and value-added process manufacturing. The old archetype could be described as localized, and commodity manufacture and assembly. These are shown in Table 6-20.

Core category	Construct	Pole	Consequence
Globalization: Low Cost	Globalized	Localized	Some use of low-cost economies for low value add manufacturing
Innovation: Process Technology	Value-added process manufacturing	Commodity manufacture and assembly	2nd tier becoming more specialist in process technologies and outsourcing simple manufacturing

Table 6-20 Supply Network Archetype - SecondT

6.7.6.2 Integration of Supply Network

This sub-section describes how the integration between SecondT and its suppliers has changed. Table 6-21 shows that the integration link in the supply network for SecondT is the use of standard components permitting customization.

Core Category	Construct	Pole	Consequence
Customer Relationship: Product Complexity	Multiple customers requiring unique products using process technology innovation	Multiple customers with identical manufactured assemblies	More box-builds and electronic assemblies being created, but each is more customized creating niche specialisms at 2nd tier. Standard components mean less waste and use on other manufactured products.

Table 6-21 Supply Network Integration - SecondT

6.7.6.3 Coevolutionary Dynamics of SecondT and the supply network

The coevolutionary dynamics of the supply network has the characteristics of the Construct column of Table 6-22: commodity suppliers are able to meet demand; suppliers can adopt process specialization; an easy dialogue with suppliers exists. The use of lean and pull (Kanban) techniques is aiding performance, which is generally becoming more consistent, in terms of delivery, cost, quality and agility.

Core Category	Construct	Pole	Consequence
Customer Relationship: Hidden costs of demand fluctuations	Commodity supplier able to meet demand	Preferred suppliers lacking inventory – stock-outs	Preferred commodity suppliers losing business as not able to deliver in time, extending the supply network to others
Innovation: Process Technology	Process specialization	Commodity assembly and manufacture	New methods for process improvement from industry and wider technological breakthroughs, providing opportunities for specialization
Survey: Easy dialogue with supplier	Easy dialogue with suppliers	Difficult dialogue with suppliers	The dynamic with the supplier permits easy dialogue
Supplier Relationship: Delivery Performance:	Consistent performance – time, cost, quality and agility	Inconsistent performance	More demanding of suppliers as more component suppliers available globally who can meet demand fluctuations to the required time, cost and quality criteria. SecondT able to meet demand and extend
Supplier Relationship: Delivery Performance	Lean and Kanban techniques	High inventory and excessive waste	Improved delivery and inventory management, becoming responsive to demand fluctuations
Survey: Lean Practice	Lean Practice	High waste	Waste is removed as a consequence of lean practices in the supply network

Table 6-22 Supply Network Coevolutionary Dynamics - SecondT

The dynamics are sometimes more like the pole column. In particular, preferred suppliers experience stock-outs, slowing the dynamic in the supply network. Commodity parts being manufactured and assembled is a core supply network capability, but has no added value or technological innovation. Dialogue can sometimes be difficult with suppliers, and performance can be hit and miss. High levels of inventory sometimes need to be held with associated cost implications, and avoidable waste happens without lean practices in place.

6.7.7 SecondT summary

This section concludes the analysis of SecondT. This 2nd tier supplier perceives the supply network structure as one that is globalized and one of increasingly value-added process manufacturing, rather than commodity manufacture and assembly. Integration in the supply chain is achieved by the use of standard components for box builds. The supply network dynamic is one where commodity suppliers meet demands, processes are specialized, there is easy dialogue, consistent performance and lean techniques. SecondT is the last case study in this chapter.

6.8 Closing Remarks

This chapter presented four new case studies and summarised an earlier case study of the three largest aerospace manufacturing primes. The empirical case studies related to an aerospace manufacturing prime, two OEMs/systems integrator and a second tier UK based manufacturer. Each case study presented a combination of results from open-ended, semi-structure or structured (repertory grid) interviews and from the survey, relating to the specific case-study firms. Results were analysed into core categories and sub-categories which were further assessed as contributing to 1. the supply network archetype, 2. integration in the supply network, 3. coevolutionary dynamics of the firm and the supply network.

This chapter has started to answer the two of questions posed in Chapter 1 relating to Phase 3 of the research: Q3b: "*What differences are there in inter-organizational characteristics at different tiers of the supplier network?*" and Q3c: *"How do supply chain dynamics relate to supply network structure?"* It has made a start to identify the nature of the supply network structure and coevolutionary dynamics. In addition it has highlighted the importance of integration in the supply network. Differences by tier have been observed.

The next chapter presents the results of the survey and so extends the results of this chapter. A comparative analysis and discussion can be found in Chapter 8.

7 AEROSPACE QUESTIONNAIRE SURVEY

"Evolution continually innovates, but at each level it conserves the elements that are recombined to yield the innovations. When a new building block is discovered at some level, it usually opens a whole range of possibilities because of the potential for new combinations with other extant building blocks. Tremendous changes and advances come."

(Holland, 1995: 80)

7.1 Introduction

This chapter has two objectives: to present the results of stage 3 of the research design and to make some attempt to validate these results. It provides statistics related to the survey returns, which provide a benchmark for future analysis.

The first section of this chapter describes how the 78 conceptual characteristics found in the literature were first revised as a result of practitioner input, and then reduced to 27 operational characteristics for the survey instrument.

The questionnaire survey was made up of two tables. Table 1 asked respondents to evaluate each of the 27 characteristics against 5 performance success criteria: Product Quality, Cost Efficiency, Delivery Precision, Technology/Innovation and Vision for the Future. Table 1 is referred to as First Order, because the evaluations attempt to find a direct, and so first order, relationship between inter-firm characteristics and supply network performance. An example is shown in Figure 7-1.

Characteristics	Success criteria factors				
Rate of characteristic to successfactor criteria	Prod	Cost	Deliv	Tech	Vision for
High (9), None ())	qual	effici	prec	inno	the future
1. Outsourcing competitive advantage	5	9	5	9	9
2. Outsourcing what is easily imitated	5	7	7	0	9
3. High level of collaborative relationship	9	9	9	9	9
4. Arms length relationships	0	0	0	0	0
5. Long-term relationship	5	7	5	5	9
6. Formal partnership	9	7	7	7	7
7. Subcontracting whole systems and sections	7	9	7	7	9
8. Flexibility of operations	3	5	9	3	7
9. Risk-sharing	0	9	0	7	7
10. Sharing knowledge	9	5	7	7	9
11. Offsets as part of sales contract	0	0	0	0	5
12. Culture of continuous improvement	9	9	9	5	9
13. Ability to handle cutural differences	7	7	7	5	7
14. High level of dominance over supplier	5	9	7	0	7
15. High level of planning and control	5	5	7	0	5
16. Easy dialogue with supplier	7	7	5	7	7
17. IT system integration	5	5	5	5	5
18. High levels of integration of chain	5	9	7	7	9
19. Responsive to market change	0	7	7	7	7
20. Transparent organisation	7	7	5	7	7
21. TQM procedures	9	7	9	7	9
22. Just-in-time delivery	3	5	9	3	7
23. Lean practice	5	7	7	5	9
24. Explorative learning practices	3	5	5	5	5
25. Investment in training	9	9	9	9	7
26. Supplier development	9	7	7	3	9
27. Monitoring supplier	3	3	3	0	7

Figure 7-1 Case example of a completed (First Order) Table 1

Table 2 asked respondents to evaluate the interdependencies of each characteristic upon every other characteristic. This is referred to as Pair-wise results, but could be described as second order effects. An example is shown in Figure 7-2. Analysis of Table 2 enables the effect of a characteristic upon every other characteristic to be evaluated.

Characteristics Strongly synergetic (+5), indiffernt effects (0), strongly conflicting (-5)	1. Outsourcing competitive advantage	2. Outsourcing what is easily imitated	3. High level of collaborative relationship	4. Arms length relationship	5. Long-term relationship	6. Formal partnership	7. Subcontracting whole systems and sections	8. Flexibility of operations	9. Risk-sharing	10. Sharing knowledge	11. Offsets as part of sales contract	12. Culture of continuous improvement	13. Ability to handle cultural differences	14. High level of dominance over supplier	15. High level of planning and control	16. Easy dialogue with supplier	17. IT system intergration	18. High levels of integration in chain	19. Responsive to market change	20. Transparent organisation	21. TQM procedures	22. Just-in-time delivery	23. Lean practices	24. Explorative learning practices	25. Investment in training	26. Supplier developm
2. Outsourcing what is easily imitated	0																									
3. High level of collaborative relationship	5	0																								
4. Arms length relationship	-5	3	-5																							
5. Long-term relationship	5	0	5	-5																						
6. Formal partnership	5	0	5	-5	5																					
7. Subcontracting whole systems and sections	5	-5	5	-5	3	5																				
8. Flexibility of operations	3	2	5	0	3	3	3																			
9. Risk-sharing	5	0	5	-5	3	5	3	2																		
10. Sharing knowledge	5	-2	5	-5	3	5	5	3	5																	
11. Offsets as part of sales contract	5	5	5	0	3	3	0	0	0	1																
12. Culture of continuous improvement	3	5	3	-3	3	3	2	3	5	5	0															
13. Ability to handle cultural differences	3	0	5	-3	3	3	3	0	0	3	3	5														
14. High level of dominance over supplier	3	5	-5	3	0	-5	3	0	-3	-3	0	-2	-2													
15. High level of planning and control	3	2	3	0	0	0	3	-2	-3	0	0	-2	0	5												
16. Easy dialogue with supplier	4	5	5	0	3	5	3	3	0	5	1	5	5	1	0											
17. IT system integration	5	0	5	-3	3	3	3	-2	0	3	0	3	0	1	3	3										
18. High levels of integration in chain	5	3	3	-5	3	3	5	0	5	3	0	3	0	2	2	3	5									
19. Responsive to market change	3	3	5	0	3	3	3	5	3	3	1	3	3	3	2	3	2	3								
20. Transparent organisation	5	3	3	-5	3	3	3	3	-2	3	0	5	3	1	0	3	4	3	3							
21. TQM procedures	5	2	2	-5	3	3	3	5	3	3	0	5	3	2	0	5	0	0	3	2						
22. Just-in-time delivery	3	3	3	0	3	3	3	3	3	0	0	3	0	2	3	3	3	3	0	0	3					
23. Lean practices	5	5	3	-5	3	3	3	5	3	3	0	5	0	2	2	5	3	3	3	0	5	5				
24. Explorative learning practices	5	2	3	-5	3	3	3	5	2	5	0	5	3	2	0	3	0	2	2	3	5	3	5			
25. Investment in training	3	2	3	-5	3	3	3	5	2	5	0	5	3	2	0	3	0	2	0	3	5	3	3	5		
26. Supplier development	3	5	3	-2	5	3	5	3	2	5	0	3	5	4	2	5	2	3	3	5	5	3	5	3	3	
27. Monitoring suppliers	3	3	3	5	3	2	3	3	3	3	0	3	3	3	3	5	0	2	3	3	3	3	2	0	0	5

Figure 7-2 Case example of a completed (Pair-Wise) Table 2

By transposing this matrix, and ignoring the sign in the transposed results, and then multiplying the matrix by itself, it is possible to calculate the effect of each characteristic upon every other characteristic. A single column with 27 rows is derived which describes inter-characteristic performance. For example, if a characteristic is perceived as interacting negatively upon most other characteristics, then its inter-characteristic effect may be negative overall. This is because ratings are on an integer scale from -5 through to +5.

Pair-wise results have been used alone to find bundles of the most synergetic characteristics identifying organizational forms. The question for this research is which Table should be used in which proportion in order to arrive at some meaning of supply network performance. The research strategy presented in Chapter 5 proposed taking three scenarios:

1) First order data only (data sets 1-9 in Figure 7-3),

2) a joint/combined analysis with equally weighted contributions from each table (data sets 10-18 in Figure 7-3), and

3) Pair-wise data alone (data sets 19-22 in Figure 7-3).

The second scenario in which combined data is used requires that equal weight is given to data from each of Tables 1 and 2. After normalization, the sum of the absolute values for each characteristic must have the same total.

Table 1 data can be analysed further by performance criteria (quality, cost, etc). All 22 possible data sets are shown in Figure 7-3. Results are presented in the next three sections: first by Performance Success Criteria (quality, cost etc) using data sets 1-5 and 10-14, second, by tier of the firm (prime, first, second) using data sets 6-8, 15-17, 19-21, and third, for the whole industry, using all cases and data sets 9, 18 and 22. The last section of this chapter examines some statistics related to the questionnaire survey.

7.2 Operationalization of Conceptual Characteristics

A weakness in the first stage of the research was the excessive number of conceptual articles. Conceptual classification usually forms a typology which represents types rather than empirical cases (Bailey, 1994). It was appropriate to start the research based on previous literature and to create as inclusive a population of characteristics as possible (McKelvey, 1975). However in order to ground the questionnaire survey in empirical evidence from the commercial aerospace manufacturing sector, the 78 characteristics found in Phase I or the Research Design (see Table 5-1) were reduced to only 27.

Part 1 (First Order Data)	Part 2 (Pair-wise Data)	Cases	Ref	Data Set
Product Quality (first column)	not used	All	1	First Order Quality
Cost Efficiency (second column)	not used	All	2	First Order Cost
Delivery Precision (third column)	not used	All	3	First Order Delivery
Technology/innovation (fourth column)	not used	All	4	First Order Technovation
Vision for the future (fifth column)	not used	All	5	First Order Vision
Weighted sum of all performances	not used	Primes	6	First Order Primes
Weighted sum of all performances	not used	Tier 1 firms	7	First Order Tier 1
Weighted sum of all performances	not used	Tier 2 firms	8	First Order Tier 2
Weighted sum of all performances	not used	All firms	9	First Order All
Product Quality (first column)	All data used	All	10	Joint Quality
Cost Efficiency (second column)	All data used	All	11	Joint Cost
Delivery Precision (third column)	All data used	All	12	Joint Delivery
Technology/innovation (fourth column)	All data used	All	13	Joint Technovation
Vision for the future (fifth column)	All data used	All	14	Joint Vision
Weighted sum of all performances	All data used	Primes	15	Joint Primes
Weighted sum of all performances	All data used	Tier 1 firms	16	Joint Tier 1
Weighted sum of all performances	All data used	Tier 2 firms	17	Joint Tier 2
Weighted sum of all performances	All data used	All firms	18	Joint All
not used	All data used	Primes	19	Pair-wise Primes
not used	All data used	Tier 1 firms	20	Pair-wise Tier 1
not used	All data used	Tier 2 firms	21	Pair-wise Tier 2
not used	All data used	All firms	22	Pair-wise All

Figure 7-3 22 Data Sets organized by three Scenarios

In order to produce a Cladogram which represented the inter-firm characteristics in the commercial aerospace supply chain, eighteen open-ended interviews were conducted in Europe, Japan and the USA with one airframe prime and with six 1st tier suppliers. Key respondents at Senior Manager and Director level with in-depth knowledge of the supply network contributed to these interviews. These interviews were recorded in confidence by the project team as part of ESRC grant RES-000-23-0845 “Modelling the Evolution of the Aerospace Supply Chain” 2005-2008.

7.2.1 Practitioner input

The interview data involved systematic coding of categories identified in the interview transcript texts similar to the approach taken with the text of the literature research. From this 5 extra character states were elicited whilst 4 character states were now found to be redundant (see Table 7-1). The revised dataset suggested the emergence of a new form of supply chain and so the Cladogram was revised as shown in Figure 7-4. Further details are provided in the papers published from the project:

(Rose-Anderssen et al., 2009a; Rose-Anderssen et al., 2008a; Rose-Anderssen et al., 2009b; Rose-Anderssen et al., 2008b; Rose-Anderssen et al., 2008c; Rose-Anderssen et al., 2008d).

New Characteristics
79 High Level of Collaborative Relationships
80 Risk Sharing
81 Sharing Knowledge
82 Easy Dialogue with Supplier
83 Lean Practices
Deleted Characteristics
09 – Supplier selection
27 – Division of labour, diversification of expertise and responsibility
52 – Intra-company integration (duplicate of characteristic 55)
78 – Subcontracting of propulsion engines

Table 7-1 Changed Characteristics after Interviews

7.2.2 Operationalization of revised characteristics

The next stage was to operationalize the remaining 79 characteristics. This was completed by the elimination of non-current characteristics and a process of consolidation of the remaining characteristics where possible. Table 7-2 shows the conceptual characteristics retained as a basis for operational characteristics. Table 7-3 shows the conceptual characteristics which are non-current and so not included in the mapping on Table 7-2.

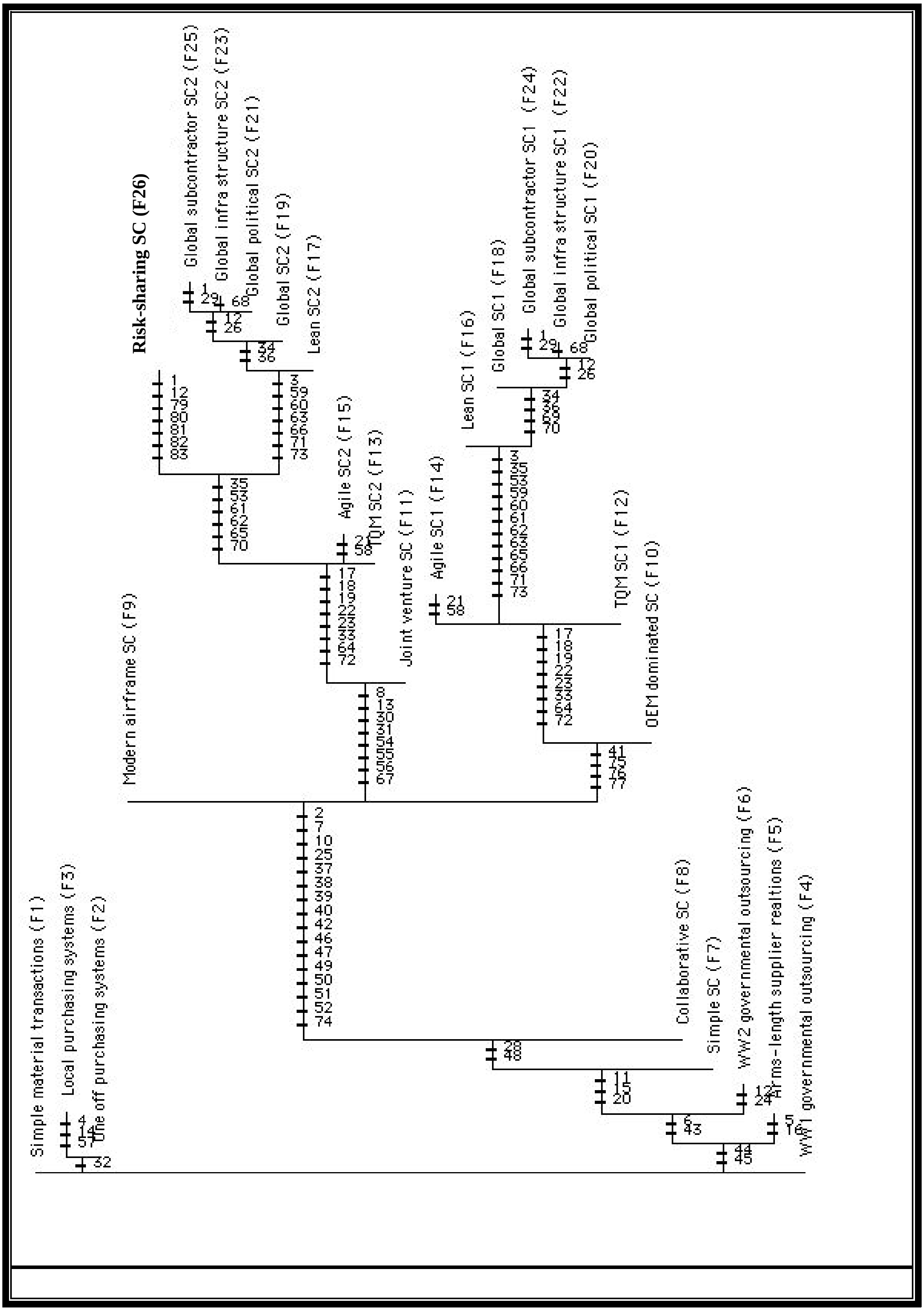


Figure 7-4 Factual Cladogram of emerging aerospace supply chains

Operational Characteristic	Conceptual				
1. Outsourcing competitive advantage	1				
2. Outsourcing what is easily imitated	2				
3. High level of collaborative relationship	7	25	48	59	79
4. Arms length relationship	5				
5. Long-term relationship	7	77			
6. Formal partnership	8				
7. Subcontracting whole systems and sections	12	20			
8. Flexibility of operations	21	58			
9. Risk-sharing	23	42	80		
10. Sharing knowledge	24	81			
11. Offsets as part of sales contract	29	68			
12. Culture of continuous improvement	35	73			
13. Ability to handle cultural differences	33	34	36		
14. High level of dominance over supplier	41				
15. High level of planning and control	43				
16. Easy dialogue with supplier	50	82			
17. IT system integration	53				
18. High levels of integration in chain	54	56			
19. Responsive to market change	58				
20. Transparent organisation	61	62			
21. TQM procedures	63	64			
22. Just-in-time delivery	65				
23. Lean practices	83				
24. Explorative learning practices	70				
25. Investment in training	71				
26. Supplier development	72				
27. Monitoring suppliers	75				

Table 7-2 Relationship between Operationalized and Conceptual Characteristics

7.2.3 Summary

This section described the process of validating and operationalizing the conceptual inter-firm characteristics found in the literature. The remaining 27 characteristics were constructed into two tables which formed the questionnaire survey.

The next section presents the validation relevant to the survey data. Figures for all survey results are contained in Appendix N.

Unused Characteristics
03 – Investing in a high-level single supplier relationship
04 – Short-term goals and expectations of suppliers
06 – Repeated transactions
09 – Supplier selection
10 – Supply chain sourcing – multiple suppliers
11 – Supply chain management
13 – Partnership sourcing
14 – Local purchasing
15 – Market approach to supply
16 – Suppliers selected on basis price
17 – Suppliers selected on basis of quality
18 – Focus on product quality
19 – Focus on distribution quality
22 – Dealing with strategic issues for the whole SC
26 – Political requirements
27 – Division of labour, diversification of expertise and responsibility
28 – Regional clusters of expertise
30 – Collective channelling of competing interests into shared interests
31 – Shared domination of supply network WAS 88
32 – One off-purchases
37 – Focus on understanding the players in the supply environment
38 – Knowing how to respond to the environment
39 – Power relationship structures
40 – Appropriate relationship according to context firm is in
44 – Organisation structures
45 – Management methods
46 – Investment in supply chain infrastructure
47 – Focus on internal and external relationships
49 – Social co-ordination and control
51 – Communication skills
55 - Intra-company integration
57 – Low levels of integration
60 – Open interdependencies
66 – Moving assembly line at airframe manufacturer
67 – Decentralised decision making
69 – Incorporating suppliers from customer's country
74 – Company performance as inter-company competence
76 – Online reverse auctions to drive down unit prices

Table 7-3 Unused Characteristics

7.3 Survey Results by Performance Success Criteria

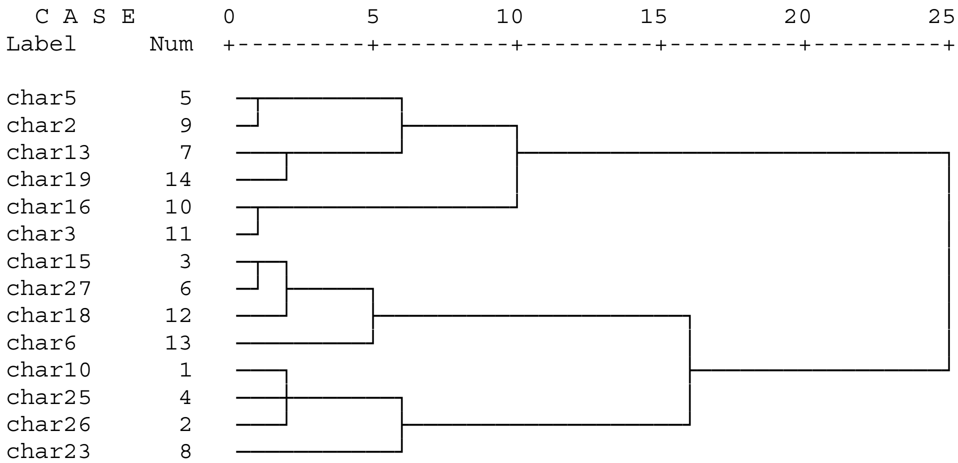
This section presents results for the five performance success criteria: Product Quality, Cost Efficiency, Delivery Precision, Technology/Innovation, and Vision for the Future. The final sub-section makes a comparison of all performance success criteria, and refers also to Chapter 6 case study results.

7.3.1 Product quality performance

This section presents the results of the questionnaire survey relating to Product Quality. Data sets 1 and 10 are examined. Data Set 1 is obtained from Table 1 of the survey instrument, relating to column 1 (Product Quality). Data Set 10 uses Table 2 pair-wise effects to adjust Data Set 1 values in order to reflect more accurately the actual performance of quality in the supply network. All cases are included in this analysis.

7.3.1.1 First order quality – Data Set 1

The most important inter-firm characteristics which achieve quality performance success, based on first order data, are sharing knowledge and supplier development. Two clusters are found in the survey data, each of which has two sub-clusters. The most highly performing sub-cluster has inter-firm characteristics of ‘Sharing Knowledge’, ‘Investment in Training’, ‘Supplier Development’ and ‘Lean Practice’. The other sub-cluster within this cluster, also contributing to high quality performance is ‘High Level of Planning and Control’ and ‘Monitoring Supplier’. The second cluster has inter-firm characteristics of ‘Long-Term Relations’, ‘Outsource Easily Imitable’ and ‘Can Handle Cultural Differences’. These results are shown in Figure 7-5. The ‘Num’ column in the dendrogram identifies the most significant inter-firm characteristics, for example, Char 10, Num 1, which is ‘Sharing Knowledge’, is relatively most significant. The method to determine significance is the coefficient of variation, which is described in full in Chapter 5 Section 4. Note that only the top 14 inter-firm characteristics are shown since including all 27 would make interpreting the dendrogram difficult and excluding them does not affect the overall results.



	cluster 1		cluster 2
char5	long term relations	char15	high level of planning and control
char2	outsource easy imitable	char27	monitoring supplier
char13	can handle cultural differences	char18	high levels of integration in chain
char19	responsive to market change	char6	formal partnership
char16	easy dialogue with supplier	**char10**	**sharing knowledge**
char3	high level collaboration	char25	investment in training
		char26	**supplier development**
		char23	lean practice

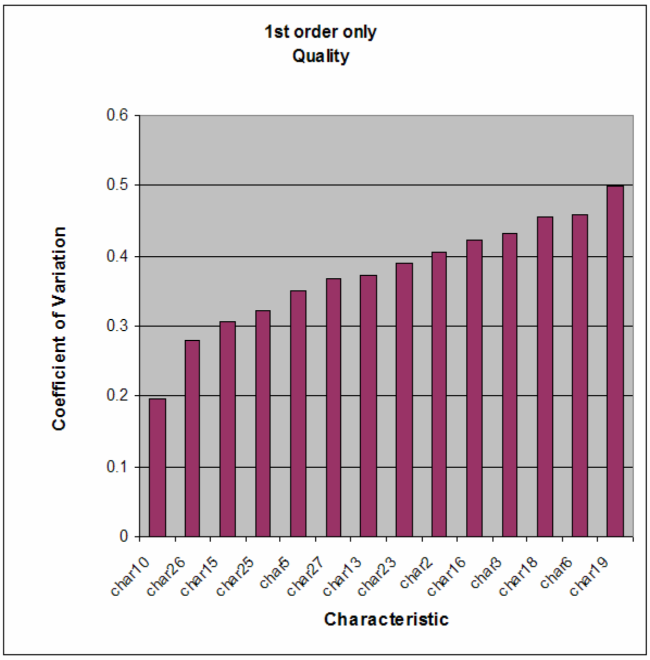


Figure 7-5 First Order Survey Results for Quality

7.3.1.2 First order and pair-wise combined quality – data set 10

The most important inter-firm characteristics which achieve quality performance success, based on combined first order and pair-wise data, are 'Formal Partnership' and ‘Lean Practice’. These inter-firm characteristics are in the same sub-cluster as ‘Supplier Development’, and in the same cluster as ‘High Level Collaboration’, ‘Easy Dialogue with Supplier’ and ‘Long Term Relations’. The second cluster has notable inter-firm characteristics of ‘Monitoring Supplier’ and ‘Outsource Easily Imitable’ (Figure 7-6).

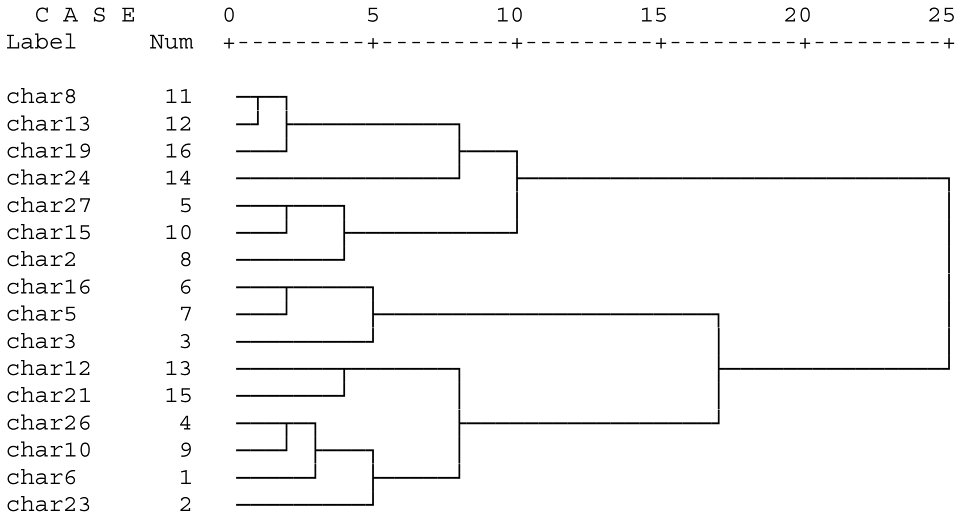
7.3.1.3 Analysis of quality - survey

The cluster analyses demonstrate that quality performance is achieved by firms pro-actively investing and controlling their suppliers. The first order data survey suggests a more collaborative (sharing knowledge, supplier development) approach but when taking into account pair-wise data, the most highly performing way is by the use of controls, such as formal partnership, lean practice and outsourcing the easily imitable. The importance of long-term relationships, easy dialogue with suppliers, and handling cultural differences are clear contributors to high quality performance. The cluster analysis demonstrates how collaboration and control together achieve high quality performance.

7.3.1.4 Results for quality - overall

This subsection examines the case study results in light of the survey results. Risk-sharing partnerships between the Prime and first tier suppliers are creating expectations of high quality, as is the use of industrial techniques such as lean. Quality features in the coevolution of the supply network as a mechanism for suppliers to learn and develop products with more added-value, increasing their chances of selection into new supply networks and also taking increasing amounts of design and manufacturing from firms higher up in the supply network. The use of quality standards is seen as an integrative devise between an OEM firm and its suppliers, enabling continuous improvement.

Reputation of the OEM firm is maintained by a tighter control over fewer numbers of high quality suppliers, creating consolidation in the supply network. Quality standards in LCEs are an ongoing challenge as firms in LCEs increasingly design and build more complex parts. The 2nd tier firm notes that there can be a high hidden cost to quality. For all firms, quality is mandatory. There is no market for poor quality performance in aerospace manufacturing.



cluster 1		cluster 2	
char8	flexible operations	char16	easy dialogue with supplier
char13	can handle cultural differences	char5	long term relations
char19	responsive to market change	char3	high level collaboration
char24	explorative learning practices	char12	culture of continuous improvement
char27	monitoring supplier	char21	TQM procedures
char15	high level of planning and control	char26	supplier development
char2	outsource easy imitable	char10	sharing knowledge
		char6	**formal partnership**
		char23	**lean practice**

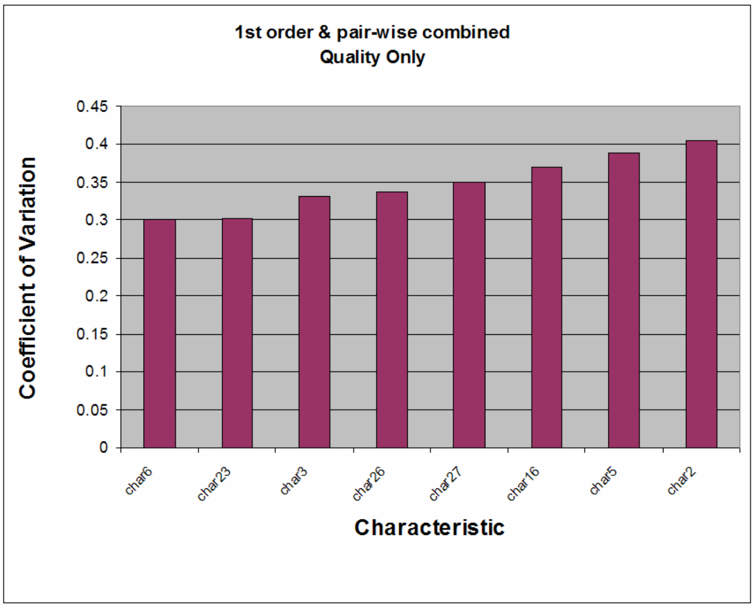


Figure 7-6 Combined First Order & Pair-wise Survey Results for Quality

The next sub-section looks at Cost Efficiency performance. Figures for the following data sets are contained in Appendix N, entitled COST ONLY.

7.3.2 Cost efficiency performance

This section presents the results of the questionnaire survey relating to Cost Efficiency. Data sets 2 and 11 are examined. Data Set 2 is obtained from Table 1 of the survey instrument, relating to column 2 (Cost Efficiency). Data Set 11 uses Table 2 pair-wise effects to adjust Data Set 2 values in order to reflect more accurately the actual performance of cost efficiency in the supply network. Cases from all firms are included in this analysis.

7.3.2.1 First order cost efficiency – data set 2

The most important inter-firm characteristics which achieve cost efficiency performance success, based on first order data, are 'High Level Collaboration' and 'Lean Practice'. There are two main clusters in the survey data. The highest performing cluster includes inter-firm characteristics for 'Lean Practice', 'TQM procedures', 'Supplier Development', 'Responsive to Market Change'. The second main cluster for cost efficiency brings together 'High Level Collaboration', 'Just in Time Delivery', 'Formal Partnership' and 'High Levels of Integration in Chain'.

7.3.2.2 First order and pair-wise combined cost efficiency – data set 11

The most important inter-firm characteristics which achieve cost efficiency performance success, based on combined first order and pair-wise data, are 'Formal Partnership' and 'Lean Practice'. These two inter-firm characteristics cluster together with 'High Level Collaboration', 'Outsource the Easily Imitable', 'Supplier Development', and 'Long Term Relations'. Two further clusters are evident. The first contains 'A Culture of Continuous Improvement', 'Responsive to Market Change', and 'TQM procedures' and the second refers to 'Monitoring Supplier' and 'High Level of Planning and Control'.

7.3.2.3 Analysis of cost efficiency - survey

The cluster analyses which examine the performance of cost efficiency demonstrate the importance of lean practices. High level collaboration and supplier development are critical to cost efficiency, as are formal partnership and responsiveness to market change. Supplier monitoring and high levels of planning and control are still embedded in practices but are not as important as the ability to adapt, to improve cost efficiency and in response to customer demand. Cost efficiency appears to perform most highly where it is embedded within a formal framework but is reflexive of needs in its operation.

7.3.2.4 Results for cost efficiency - overall

This subsection examines the case study results in light of the survey results. Cutting costs was perceived as the main driver to achieve competitive advantage. The main method to cut costs for the Prime was via risk-sharing partnerships, whereas for the OEMs and the 2nd tier firm, it was the availability of cheap labour in low cost economies, so that globalization has become a strategy for cost reduction.   For the Prime, the use of standard product interfaces was also seen as a way of keeping costs lower. Lean practice as a means of reducing waste and cost was not a prominent method as the notion of too much lean was also a risk. This is in stark contrast to the survey where it is perceived to be the largest contributor to cost efficiency. Outsourcing the easily imitable, which is largely the first wave of manufacturing to print contracts which have already been outsourced to low-cost economies, is an important factor in the survey. This is an area for further research. It is possible that whilst costs are low in LCEs, that cost efficiency is not a given, maybe due to the hidden costs involved.

7.3.3 Delivery precision performance

This section presents the results of the questionnaire survey relating to Delivery Precision. Data sets 3 and 12 are examined. Data Set 3 is obtained from Table 1 of the survey instrument, relating to column 3 (Delivery Precision). Data Set 12 uses Table 2 pair-wise effects to adjust Data Set 3 values in order to reflect more accurately the actual performance of delivery precision in the supply network. All cases are included in this analysis. Figures for the following data sets are contained in Appendix N, entitled DELIVERY ONLY.

7.3.3.1 First order delivery precision – data set 3

The most important inter-firm characteristics which achieve delivery precision performance success, based on first order data, are ‘Formal Partnership’ and ‘Supplier Development’. These two inter-firm characteristics occur in the same cluster with ‘High Levels of Integration in Chain’, ‘Flexible Operations’ and ‘IT System Integration’. The second high performing cluster for delivery precision contains ‘Just-in-Time Delivery’, ‘Lean Practice’ and ‘Long Term Relations’.

7.3.3.2 First order and pair-wise combined delivery precision – data set 12

The most important inter-firm characteristics which achieve delivery precision performance success, based on combined first order and pair-wise data, are ‘Formal Partnership’ and ‘Lean Practice’. These cluster with ‘Long Term Relations’, ‘TQM procedures’, ‘High Level of Planning and Control’ and ‘Flexible Operations’. The second cluster for delivery precision success contains ‘Supplier Development’, ‘Monitoring Supplier’, ‘High Level Collaboration’, and ‘Easy Dialogue with Supplier’

7.3.3.3 Analysis of delivery precision - survey

The cluster analyses which examine the performance of delivery precision demonstrate the importance of formal partnership. Supplier development, flexible operations and lean practice are critical to delivery precision success. First order results highlight the importance of bringing together integrative practices and enablers to facilitate delivery precision. The combined results reinforce the importance of planning and lean practice. Supplier development, monitoring and easy dialogue contribute to delivery precision as they have done for product quality and cost efficiency.

7.3.3.4 Results for delivery precision - overall

This subsection examines the case study results in light of the survey results. Globalization is achieving lower costs but the maturity of firms in LCE with respect to quality and delivery precision is an issue for the Prime. The increase in specialist systems suppliers who supply to a diversified based of customers is also creating a risk to delivery precision as other customers may have more leverage with the specialists. Large demand fluctuation brings with it a risk of mortality to the supplier, particularly during the up-turn in demand.

For the OEM, good delivery performance to the MRP (Materials Resource Plan) is connected with good long-term relationships and trustworthiness of suppliers. The 2nd tier supplier notes that changes made by a supplier to adopt just-in-time and 'kanban' methods, increases risks if the supply chain cannot deliver to timescale. Demand fluctuations exacerbate these difficulties. For the 2nd tier supplier, consistent performance includes a focus on time and agility, and these demands upon suppliers are increasing as there is more competition available globally. The case studies reinforce the survey results.

7.3.4 Technology innovation performance

This section presents the results of the questionnaire survey relating to Technology Innovation. Data sets 4 and 13 are examined. Data Set 4 is obtained from Table 1 of the survey instrument, relating to column 4 (Technology Innovation). Data Set 13 uses Table 2 pair-wise effects to adjust Data Set 4 values in order to reflect more accurately the actual performance of technology innovation in the supply network. All cases are included in this analysis. Figures for the data sets are contained in Appendix N, entitled TECHNOVATION ONLY.

These last two performance success criteria are different from the first three, which are operational and tangible. Technology Innovation is concerned with the supplier's ability to implement new product and/or process technologies, or to innovate in other technological ways, for example, creating software or using Information Communication Technologies (ICT). The last performance success criteria Vision for the Future' examines whether or not the supplier has been clear about its future and how it will contribute or create that future.

7.3.4.1 First order technology innovation – data set 4

The most important inter-firm characteristics which achieve Technology Innovation performance success, based on first order data, are ‘Investment in Training’ and a ‘Culture of Continuous Improvement’. These two inter-firm characteristics cluster together with ‘Flexible Operations’, ‘Transparent Organization’, and ‘Explorative Learning Practices’. The focus of the characteristics in this cluster is learning and improvement. The second cluster of high performing Technology Innovation characteristics include ‘Easy Dialogue with Supplier’, ‘High Level Collaboration’, ‘Long Term Relations’ and ‘Risk-Sharing’. These two clusters highlight the nature of technology innovation – needing both exploration and facilitation.

7.3.4.2 First order and pair-wise combined technology innovation – data set 13

The most important inter-firm characteristics which achieve Technology Innovation performance success, based on combined first order and pair-wise data, are ‘Lean Practice’ and ‘Culture of Continuous Improvement’. These two characteristics are in the same cluster with ‘Explorative Learning Practices’, ‘Flexible Operations’ and ‘Supplier Development’. The next two most important characteristics are ‘High Level Collaboration’ and ‘Easy Dialogue with Supplier’ which are in a second cluster, together with ‘Formal Partnership’ and ‘Long Term Relations’. These clusters, with the interesting inclusion of lean practices, reflect the First Order results of exploration and facilitation.

7.3.4.3 Analysis of technology innovation - survey

The cluster analyses which examine the performance of Technology Innovation demonstrate the importance of exploration, in which there is investment in training, explorative learning practices, and a culture of continuous improvement. The second cluster in both data sets show that a concurrent enabling facilitation framework which includes an easy dialogue with supplier, high level collaboration and long term relations also contributes highly to technology innovation success.

7.3.4.4 Results for technology innovation - overall

This subsection examines the case study results in light of the survey results. Innovation is one of the core categories created to classify the results for the Prime. This category encompasses continuous improvement in the manufacturing process, increasing turns and reducing waste. R&D collaboration with suppliers is important to the creation of 'blurred technology' of benefit to the Prime and the supplier. Technological leadership and the drive to invent, trial and implement new products and processes, is balanced with robust risk management. For the Prime, ICT is a key enabler permitting the integration of suppliers and global collaboration.

OEM solutions, based on new technologies often driven by customer conceptualizations, are often not immediately solvable, so experimentation and testing is needed. Also, OEMs are working with fewer preferred suppliers, whose technology roadmaps are aligned to their own and with whom technology partnerships can be implemented. Automation using technology is perceived as a way of removing labour costs, rather than shifting them to LCEs. For the second tier firm, process technologies are becoming a focus to provide competitive edge, creating a dynamic in the supply network whereby opportunities might be created for specialization.

The case studies support the survey results and affirm the importance of innovation technology as a key performance success criteria for aerospace manufacturing firms.

In a comparative study (Nelson, 1993) national innovation systems were found to reflect differences in the priorities and circumstances of the economies and political circumstances. Size and the level of affluence was a major differentiator. Strong defence programmes and so R&D investment explained smaller size countries having large national innovation systems. This suggests that low cost economies are not yet the locations for innovation.

7.3.5 Vision for the future performance

This section presents the results of the questionnaire survey relating to Vision for the Future. Data sets 5 and 14 are examined. Data Set 5 is obtained from Table 1 of the survey instrument, relating to column 5 (Vision for the Future). Data Set 14 uses Table 2 pair-wise effects to adjust Data Set 5 values in order to reflect more accurately the actual performance of Vision for the Future in the supply network. All cases are included in this analysis. Figures for the following data sets are contained in Appendix N, entitled VISION ONLY.

7.3.5.1 First order vision for the future – data set 5

The most important inter-firm characteristics which achieve Vision for the Future performance success, based on first order data, are 'Easy Dialogue with Supplier' and 'Investment in Training'. These appear in the same cluster as 'Culture of Continuous Improvement' and 'Long Term Relations'. This first cluster gives priority to inter-firm characteristics that are long-term. A second cluster is evident for Vision for the Future. Inter-firm characteristics that are high performing include 'Lean Practice', 'Formal Partnership', 'Flexible Operations', 'TQM procedures' and 'Responsive to Market Change'. This second cluster of characteristics is based on current practices which are desirable for the future.

7.3.5.2 First order and pair-wise combined vision for the future – data set 14

The most important inter-firm characteristics which achieve Vision for the Future performance success, based on combined first order and pair-wise data, are 'Formal Partnership' and 'Lean Practice'. These appear together in a sub-cluster with 'Investment in Training'. Three other sub-clusters appear in the same cluster, the first lead by 'TQM procedures', the second with 'Supplier Development' and 'Explorative Learning Practices', the third with 'Easy Dialogue with Supplier' and 'Culture of Continuous Improvement'. A second distinct cluster is evident which has characteristics 'Long Term Relations' and 'High Level Collaboration'.

7.3.5.3 Analysis of vision for the future - survey

The cluster analyses which examine the performance of Vision for the Future demonstrate the importance of two aspects of the future, the first is investment in order to improve future capabilities, and includes long term relations, high level collaboration, investment in training, culture of continuous improvement and easy dialogue with the supplier. The second set of characteristics is focused on current needs and includes formal partnership, lean practice, and TQM procedures.

7.3.5.4 Results for vision for the future - overall

This subsection examines the case study results in light of the survey results. The case study of the Prime demonstrated a number of aspect in which it was establishing a vision for the future and considering how the supply network would play its part. It is proactively looking at how to improve network performance by evolving the current supply network into one fit for the future. Trial and error is part of the collaboration process in the attempt to find the right mix of suppliers for supply network evolution. Its business model is also changing to focus on services rather than one of products. It expects more business to arise after the delivery of jetliners than it does today. The first OEM case study described the vision of this firm to be a first tier supplier and leading global provider of innovative solutions. The firm has implemented a strategy to reconfigure itself, via centralization and rationalization, in order to better leverage the supply network.

The second OEM case study described a vision in which jetliners were not purchased and that flight was sold by the hour. This vision requires collaboration across the entire supply network to resolve business models. As LCEs develop and demand some measure of manufacturing within their own nations for the jetliners they will buy for themselves, the future of jetliner design and engineering is set to move increasingly to these economies. For the future, new business models will be required throughout the supply chain as it moves away from maintenance and repair profits towards providing services (flight) by the hour thereby taking a long-term focus.

The case studies show how firms are selecting those suppliers which are aligned to their own vision and technology road-maps, and which are developing new pathways for the future. Vision is a critical success factor for the performance of the supply network today and for the future.

7.3.6 A learning model

This sub-section seeks to confirm the results of the cluster analysis via an alternative means. Within the scope of the project "Modelling the Evolution of the Aerospace Supply Chain" identified in the Acknowledgement, a learning model was created (Allen et al., 2008b) and was run using the responses to the questionnaire survey.

The basic form of the model is that of a supply chain growing from an initial simple structure to a complex, multi-practice structure that reflects the dimensions of performance required by the "market" environment and the learning of the supply network management. The basic form is that of a logistic equation as shown in Equation 7-1.

$$\frac{dS}{dt} = bS(1 - \frac{S}{N}) - mS$$

Equation 7-1 Logistic Equation

S is the size of the supply chain, b is a growth rate, m an attrition rate and N some limiting size of the market. If the supply network S is seen as a sum of its constituent practices p(k) then we can imagine a similar equation in which the practices grow according to their suitability in the particular demand environment. We can write an equation for the practice k as shown in Equation 7-2.

$$\frac{dp(k)}{dt} = b(k)p(k)\left(1 - \frac{p(k)}{N}\right) - mp(k)$$

Equation 7-2 Logistic Equation using Practices

S is the sum of the practices p(k). The has a stationary solution in which the size of the supply chain is the sum of the practices and these have sizes that are simply a reflection of their contribution to performance given by N(1 – m(k)/b(k)). When b(k) is small then the contribution is small, and if b(k) is less than m(k) there is no contribution at all. This corresponds to the idea that m(k) represents the costs of implementation of a practice and so if a practice is to be retained then it must at least increase performance by more than the costs of implementing it.

However, this equation assumes that the practices are independent of each other and so we need to amend it by including in the growth rate b a term that allows for the synergy or conflict with the other practices present. The calculation for b(k) is shown in Equation 7-3.

$$b(k) = b(k) * (1 + \alpha \sum_{k'} \sigma(k, k') p(k'))$$

Equation 7-3 Growth rate for Logistic Equation

Where α is a factor scaling the first and second order effects, and σ(k,k') is the pair interaction between practices k and k', which can be synergetic, conflicting or neutral. This non-linear growth term introduces the presence or absence of other practices into the growth of each one and so we can explore their combined dynamics - particularly as practices are added.

The overall model therefore allows us to simulate the learning process of managers as they experiment with the introduction of new practices and discover how much they really improve performance. Over time, the supply network will contain a mix of practices that are on the whole synergetic, but because the desired mix cannot be known beforehand, the experimental nature of the process may well lead not only the to best possible bundle but also get stuck in some sub-optimal structure.

Results from the Learning Model for **Quality** are, that characteristics 12, 18, 21, 23 and 26 are universal:

- 12 is culture of continuous improvement
- 18 is High levels of integration of the supply chain
- 21 is TQM
- 23 is Lean Practice
- 26 is Supplier development

High Levels of Integration in the supply chain is missing from the survey clustering results for Scenario 2 (Table 1 and Table 2 combined). See Figure 7-7.

	cluster 1		cluster 2
char8	flexible operations	char16	easy dialogue with supplier
char13	can handle cultural differences	char5	long term relations
char19	responsive to market change	char3	high level collaboration
char24	explorative learning practices	char12	culture of continuous improvement
char27	monitoring supplier	char21	TQM procedures
char15	high level of planning and control	char26	supplier development
char2	outsource easy imitable	char10	sharing knowledge
		char6	**formal partnership**
		char23	**lean practice**

Figure 7-7 Scenario 2: Combined Table 1 and Table 2 survey results for Product Quality

Results from the Learning Model for **Cost Efficiency** are, that characteristics 5, 10, 12, 19, 21, 23 and 26 are universal

- 5 is long-term relationships
- 10 is about sharing knowledge
- 12 is the culture of continuous improvement
- 19 is responsive to market change
- 21 is TQM
- 23 is lean
- 26 is supplier development

Figure 7-8 shows results survey results for Scenario 2 (Table 1 and Table 2 combined) for Cost Efficiency. These concur fully with the Learning Model results.

	cluster 1		cluster 2		cluster 3
char27	monitoring supplier	char19	responsive to market change	char5	long term relations
char15	high level of planning and control	char8	flexible operations	char16	easy dialogue with supplier
char18	high levels of integration in chain	char10	sharing knowledge	**char6**	**formal partnership**
char24	explorative learning practices	char12	culture of continuous improvement	char2	outsource easy imitable
char13	can handle cultural differences	char21	TQM procedures	char3	high level collaboration
				char23	**lean practice**
				char26	supplier development

Figure 7-8 Scenario 2: Combined Table 1 and Table 2 survey results for Cost Efficiency

Results from the Learning Model for Delivery Precision are that characteristics 5, 18, 19, and 22 are universal:

- 5 is long term relationship
- 18 is high levels of integration of the supply chain
- 19 is responsive to market change
- 22 is Just-in-time delivery

Just-in-time delivery is missing from the survey results. Figure 7-9 shows results survey results for Scenario 2 (Table 1 and Table 2 combined) for Delivery Precision.

	cluster 1		cluster 2
char6	**formal partnership**	char13	can handle cultural differences
char21	TQM procedures	char19	responsive to market change
char23	**lean practice**	char27	monitoring supplier
char15	high level of planning and control	char2	outsource easy imitable
char12	culture of continuous improvement	char16	easy dialogue with supplier
char8	flexible operations	char26	supplier development
char19	responsive to market change	char18	high levels of integration in chain
char10	sharing knowledge	char3	high level collaboration
char5	long term relations	char24	explorative learning practices

Figure 7-9 Scenario 2: Combined Table 1 and Table 2 survey results for Delivery Precision

Results from the Learning Model for Innovation and Technology are that characteristics 1, 3, 10 and 12 are universal:

- 1 is outsourcing competitive advantage
- 3 is high levels of collaborative relationship
- 10 is about sharing knowledge
- 12 is the culture of continuous improvement

Outsourcing competitive advantage and sharing knowledge are missing from the survey results. Figure 7-10 shows results survey results for Scenario 2 (Table 1 and Table 2 combined) for Innovation and Technology.

	cluster 1		cluster 2
char8	flexible operations	char16	easy dialogue with supplier
char19	responsive to market change	char6	formal partnership
char21	TQM procedures	char3	high level collaboration
char12	**culture of continuous improvement**	char5	long term relations
char24	explorative learning practices		
char26	supplier development		
char23	**lean practice**		
char25	investment in training		

Figure 7-10 Scenario 2: Combined Table 1 and Table 2 survey results for Innovation and Technology

Results from the Learning Model for Vision for the Future are that characteristics 1, 3, 5, 9, 10, 16 and 25 are universal:

- 1 outsourcing competitive advantage
- 3 high levels of collaborative relationship
- 5 long term relationships
- 9 is risk sharing agreements
- 10 is sharing knowledge
- 16 is easy dialogue with suppliers
- 25 is investment in training

Outsourcing competitive advantage, risk sharing agreements and sharing knowledge are missing from the survey results. Figure 7-11 shows results survey results for Scenario 2 (Table 1 and Table 2 combined) for Innovation and Technology.

	cluster 1		cluster 2
char8	flexible operations	char5	long term relations
char19	responsive to market change	char3	high level collaboration
char21	TQM procedures		
char26	supplier development		
char24	explorative learning practices		
char6	**formal partnership**		
char23	**lean practice**		
char25	investment in training		
char12	culture of continuous improvement		
char7	subcontract whole systems		
char16	easy dialogue with supplier		

Figure 7-11 Scenario 2: Combined Table 1 and Table 2 survey results for Vision for the Future

There are some gaps between the Learning Model results and the survey results for Scenario 2, but overall they are in agreement. Some specific characteristics are worthy of investigation, such as sharing knowledge and outsourcing competitive advantage.

7.3.7 Summary

This section presented the results of the questionnaire survey relating to the five Performance Success Criteria: Product Quality, Cost Efficiency, Delivery Precision, Technology/Innovation, and Vision for the Future. Figure 7-12 demonstrates the characteristics which are important for all five performance success criteria. NOTE: the table shows inverse coefficient of variation, so that the tallest readings are the most significant. The values shown are for the Combined First Order and Pair-Wise data sets. Overall, the inter-firm characteristics most important for all fives performances are formal partnership and lean practice.

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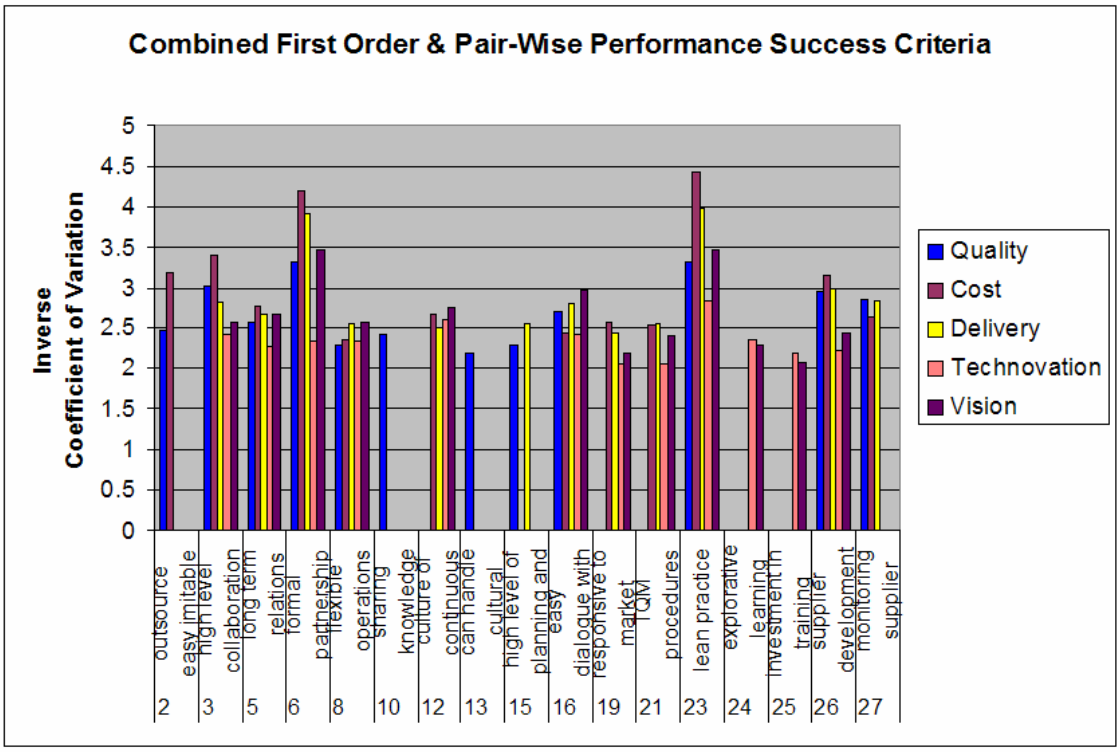

Figure 7-12 Combined First Order and Pair-Wise Performance Success Criteria

7.4 Survey Results by Supply Network Tier

This section presents survey results for three tiers in the Supply Network: Prime, OEM 1st tier and 2nd tier manufacturer. For each tier, three scenarios are considered: First Order data (Table 1), Combined First Order and Pair-Wise data (Tables 1 and 2), and Pair-Wise data only (Table 2). In total, 9 data sets are examined: For the Prime: 6, 15 and 19; for Tier 1: 7, 16 and 20; and for Tier 2: 8, 17 and 21. For each tier, there is a cross-reference to Chapter 6 case study results. Detailed dendrograms and charts are included in Appendix N. The final sub-section compares the three tiers.

7.4.1 Performance of the primes

This section presents the results of the questionnaire survey relating to the Performance of the Primes. Three data sets are examined. The first is Data Set 6 which uses the equally weighted sum of all 5 performance criteria from Table 1. The second is Data Set 15 which uses Table 2 pair-wise effects to adjust Data Set 6 values in order to more accurately reflect the actual performance of the Prime in the supply network. The third is Data Set 19 which uses only Table 2 pair-wise effects. Only those cases relating to the Primes are included in this analysis.

7.4.1.1 First order sum – primes – data set 6

In this data set only cases relating to firms which are Primes are examined. The weighted sum of all performances from Table 1 is normalized and clustered using Ward's Method. The characteristics of most significance are 'Lean Practice' and 'High Level of Planning & Control'. Both of these belong to the first main cluster, albeit to different sub-clusters. Clustered with 'Lean Practice' are characteristics relating to 'Formal Partnership', 'Flexible Operations', 'Supplier Development' and 'High Level Collaboration'. These characteristics require collaboration between both primes and their 1st tier suppliers. Clustered with 'High Level of Planning & Control' are 'Just-in-Time Delivery', 'Outsource the Easily Imitable' and 'Monitoring Supplier'; these characteristics relate to control of suppliers. The second cluster contains characteristics relating to longer term embedding of the relationship and includes 'Sharing Knowledge', TQM Procedures' and 'Long Term Relations'.

7.4.1.2 First order sum and pair-wise combined – primes – data set 15

The most important inter-firm characteristics to achieve performance success for the Primes based on combined first order and pair-wise data, are 'Flexible Operations' and 'Lean Practice'. These characteristics are in the same sub-cluster as 'High Level Collaboration' and 'Formal Partnership'. The second sub-cluster in the same cluster has 'Sharing Knowledge' with 'Long Term Relations' and 'Outsourcing Competitive Advantage'. This first cluster addresses the need for waste reduction, the need for adaptation and the means to achieve this in a framework of partnership and long-term relationships. The cluster also recognizes the paradox of outsourcing of competitive advantage for higher performance success. A second cluster is apparent and contains ‘Responsive to Market Change’, ‘Just-in-Time Delivery’ and ‘Can Handle Cultural Differences’. These characteristics recognize the need to adapt to changes in demand, supported by a just-in-time delivery perspective and the ability to handle cultural matters.

7.4.1.3 Pair-wise – primes – data set 19

For the primes there are two distinct main clusters. The most significant characteristics ‘Can Handle Cultural Differences’ and ‘Flexible Operations’ are in the first main cluster, albeit in separate sub-clusters. Clustered with ‘Can Handle Cultural Differences’ is ‘Responsive To Market Change’ bringing together skills for diversity with market awareness. Clustered with ‘Flexible Operations’ are characters relating to operational efficiency, including ‘Just-In-Time Delivery’, ‘Investment In Training’ and ‘Lean Practice’ softened by the characteristic ‘Easy Dialogue With Supplier’. In the second main cluster there are three sub-clusters. The first of the sub-clusters brings together ‘Sharing Knowledge’ with ‘Long Term Relations’. The second sub-cluster connects ‘Risk-Sharing’ with ‘Formal Partnership’, ‘TQM Procedures’, ‘Outsourcing Competitive Advantage’ and a ‘Culture Of Continuous Improvement’. The final sub-cluster brings in ‘High Level Collaboration’. This second main cluster is therefore concerned with long-term relations and related opportunities for collaboration.

7.4.1.4 Analysis of primes - survey

There are three groups of inter-firm characteristics which are common to each of the data sets described above. The dominant group is concerned with ‘High Level Collaboration’, and is associated with ‘Lean Practice’, ‘Formal Partnership’, ‘Flexible Operations’. The group brings together formality and the benefits of high-level collaboration with operational adaptability and a focus on waste reduction. These are the ideal outcomes for the Primes.

The second group is focused on ‘Just-in-Time Delivery’ and being ‘Responsive to Market Change’. It brings in the importance of ‘Can Handle Cultural Differences’ and other elements of monitoring and planning and control. This group of inter-firm characteristics is operational and delivery focused.

The third group introduces ‘Sharing Knowledge’ and ‘Long Term Relations’. The inter-firm characteristics of ‘TQM Procedures’ and ‘Outsourcing Competitive Advantage’ are also included, with a ‘Culture Of Continuous Improvement’ and ‘Risk-Sharing’. This group is therefore concerned with learning and quality improvement. It also balances outsourcing competitive advantage with risk-sharing.

The case study of the Prime identified the importance of formal partnership in its look at structure and the need for the dynamics of the operational supply network to cope with large demand fluctuations within a culture of continuous improvement. The specialization of suppliers and their increasing role in delivering design and integration work previously carried out by the Prime is exactly the outsourcing of competitive advantage. The case study highlighted that the Prime’s focus on the quality management of suppliers, investment in supplier training and continuous improvement of production.

7.4.1.5 Summary

This section presented the results of the questionnaire survey which were completed by individuals working at the Primes. Figure 7-13 demonstrates the characteristics which are important for all three methods of data analysis. NOTE: the table shows inverse coefficient of variation, so that the tallest readings are the most significant.

‘Lean Practice’ is overall the inter-firm characteristic of most significance, following by ‘Flexible Operations’, ‘Formal Partnership’, and ‘High Level Collaboration’.

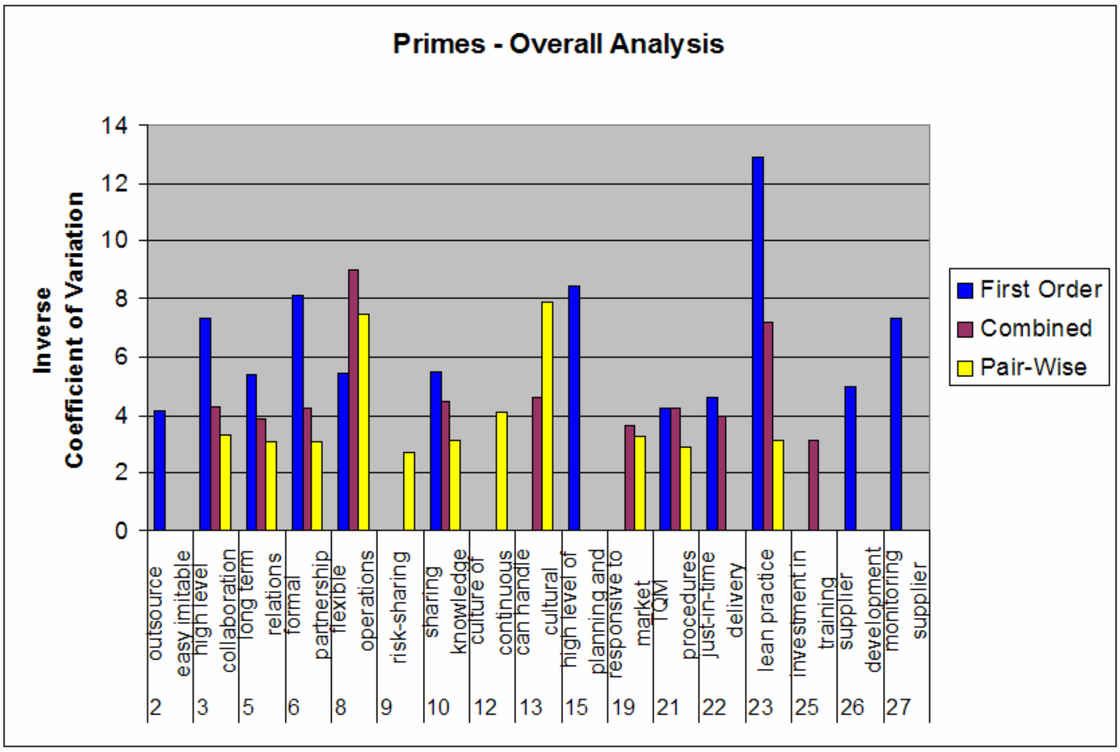

Figure 7-13 Primes - Significant Inter-Firm Characteristics

7.4.2 Performance of 1st tier

This section presents the results of the questionnaire survey relating to the Performance of the Tier 1 firms. Three data sets are examined. The first is Data Set 7 which uses the equally weighted sum of all 5 performance criteria from Table 1. The second is Data Set 16 which uses Table 2 pair-wise effects to adjust Data Set 7 values in order to more accurately reflect the actual performance of the Tier 1 firms in the supply network. The third is Data Set 20 which uses only Table 2 pair-wise effects. Only those cases relating to the Tier 1 firms are included in this analysis.

7.4.2.1 First order sum –1st tier – data set 7

This data set contains only those cases relating to firms which are 1st tier to the Primes. Such firms are systems integrators. The weighted sum of all performances from Table 1 is normalized and clustered using Ward's Method. The characteristics of most significance are 'Sharing Knowledge' and 'Subcontract Whole Systems'; both belong to the first main cluster, albeit to different sub-clusters. Clustered with 'Sharing Knowledge' are 'TQM Procedures' and 'Lean Practice'. Lean practice is thus perceived as part of longer term relationship development. Clustered with

‘Subcontract Whole Systems’ are ‘Formal Partnership’ and ‘Easy Dialogue with Supplier’; whilst there is formality in subcontracting, it is mediated by easy dialogue. The second cluster brings together characteristics relating to flexibility and responsiveness, including ‘Flexible Operations’, ‘High Level of Planning & Control’ and ‘Responsive to Market Change’. The final cluster which is most different from the other clusters contains characteristics relating to training and improvement, including ‘Investment in Training’, ‘Culture of Continuous Improvement’ and ‘High Level Collaboration’.

7.4.2.2 First order sum and pair-wise combined – 1st tier – data set 16

Taking both first order and pair-wise results, we find two clusters of inter-firm characteristics. The first contains the top three highest performing characteristics ‘Sharing Knowledge’ and ‘Culture of Continuous Improvement’, ‘Investment in Training’ together with ‘Supplier Development’. This indicates that first tier firms perceive the highest performance to arise from learning and continuous improvement. Also in this cluster are a further two sub-clusters. The first contains ‘Monitoring Supplier’ and ‘Flexible Operations’. This reflects the adaptability needed in the supply network at this tier. The second has ‘Lean Practice’, ‘Formal Partnership’ and ‘Risk-Sharing’ noting the influence of the Primes. The second cluster contains ‘High Level Collaboration’ and ‘Easy Dialogue with Supplier’.

7.4.2.3 Pair-wise – 1st tier – data set 20

For first tier firms, we find the majority of characteristics clustered in the first main cluster. A greater number of characteristics are included in the Tier 1 cluster analysis because the low coefficient of variation meant that a great deal more of the characteristics were reliable. The first main cluster has three sub-clusters, the first of which has the most significant characteristics ‘Investment in Training’ and ‘Monitoring Supplier’. These characteristics cluster with ‘Risk Sharing’, ‘Can Handle Cultural Differences’ and ‘Outsource the Easily Imitable’. This cluster takes a risk-oriented perspective to supplier relations. The second sub-cluster is focused on learning and agility with characteristics of ‘Culture of Continuous Improvement’, ‘Supplier Development’, ‘Responsive to Market Change’, ‘Flexible Operations’ and

'Sharing Knowledge'. The final sub-cluster brings together 'Lean Practice' and 'Formal Partnership'. The second main cluster brings together 'Long Term Relations' and 'Easy Dialogue with Supplier' with 'High Level Collaboration'

7.4.2.4 Analysis of 1st tier - survey

This sub-section looks at inter-firm characteristics which are consistently clustered together in all three analyses, in order to create groups of inter-firm characteristics that are particular meaningful for 1st tier firms. There are three noticeable groups.

The most dominant group brings together inter-firm characteristics relating to collaboration, learning and improvement. Prominent characteristics include a 'Culture of Continuous Improvement', 'High Level Collaboration', 'Easy Dialogue with Supplier', 'Investment in Training' and 'Sharing Knowledge'.

A second group raises the importance of adaptation and flexibility. Relevant inter-organizational characteristics include: 'Flexible Operations' and 'Responsive to Market Change'.

The last group associates 'Formal Partnership' with 'Risk-Sharing' and 'Lean Practice'. This is similar to one of the Prime's groups of inter-firm characteristics; however it is not as dominant for 1st tier firms.

The two case studies of 1st tier firms help to describe the logic of these groups. For OEM(A), the need to collaborate, have dialogue, and to share information in a process of continuous improvement is particularly applicable when considering the integration that is required of manufacturing designs and the adoption of standards in the 1st tier firm's supply network. The dynamic of supplier improvement is a feedback from investment in training and supplier development.

In the case study of OEM(B), the structure of the supply network was described as systematized, cost efficient and consolidated. This reflects the last group of inter-firm characteristics with 'Formal Partnership', 'Risk-Sharing' and 'Lean Practice' appearing together. Integration at this 1st tier firm, relating to the adoption of standards and sharing knowledge for increased performance reflects the prominent characteristics of ‘Continuous Improvement’ and ‘Sharing Knowledge’.

‘Flexible Operations’ and ‘Responsive to Market Change’ whilst not overt in the 1st tier analysis are apparent as these firms have been able to adapt to increased requirements and a focus on systems solutions. The need for flexibility and adaptation is more noticeable with respect to the case study of the Prime, who perceives significant demand fluctuations in the market place.

7.4.2.5 Summary

This section presented the results of the questionnaire survey which were completed by individuals working at first tier firms. Figure 7-14 demonstrates the characteristics which are important for all three methods of data analysis. NOTE: the table shows inverse coefficient of variation, so that the tallest readings are the most significant.

Sharing knowledge, culture of continuous improvement, flexible operations, high level collaboration

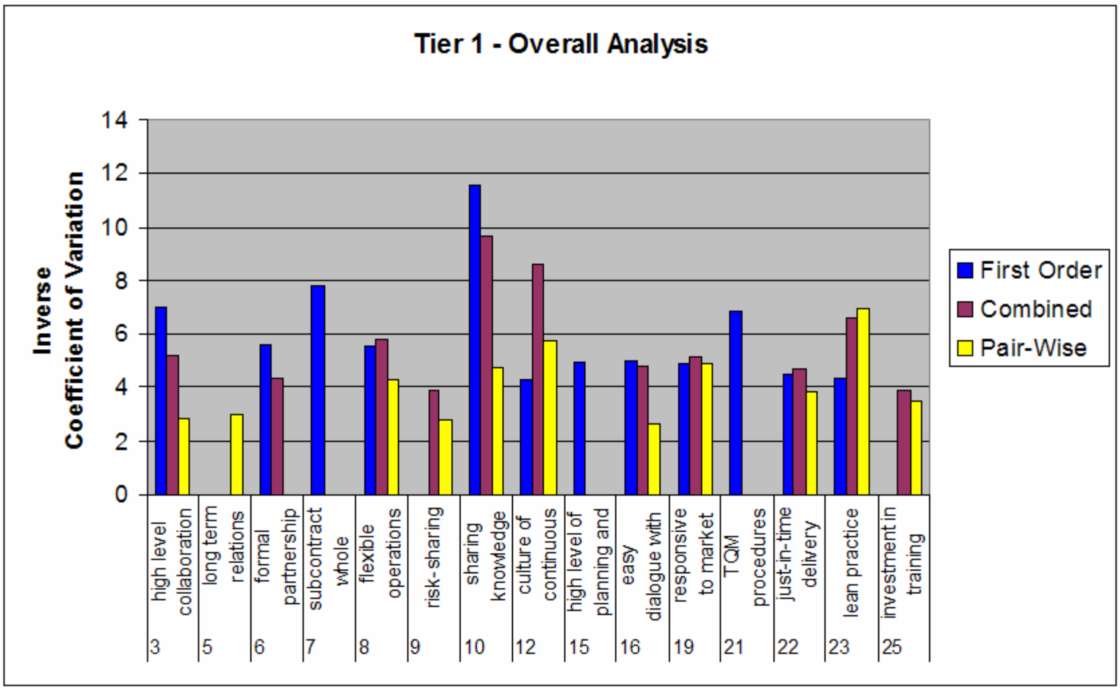

Figure 7-14 1st tier Significant Inter-Firm Characteristics

7.4.3 Performance of 2nd tier

This section presents the results of the questionnaire survey relating to the performance of Tier 2 firms. Three data sets are examined. The first is Data Set 8 which uses the equally weighted sum of all 5 performance criteria from Table 1. The second is Data Set 17 which uses Table 2 pair-wise effects to adjust Data Set 8 values in order to more accurately reflect the actual performance of the Tier 2 firms in the supply network. The third is Data Set 21 which uses only Table 2 pair-wise effects. Only those cases relating to the Tier 2 firms are included in this analysis. Such 2nd tier firms are naturally product manufacturers and parts assemblers.

7.4.3.1 First order sum – 2nd tier – data set 8

The characteristics of most significance are 'Can Handle Cultural Differences' and 'Long Term Relations'; each appears in a separate main cluster. The first cluster has two sub-clusters. 'Long Term Relations' is clustered with 'Outsource Easily Imitable' and 'TQM Procedures' along with other characteristics relating to standardisation of practice and knowledge sharing. A second sub-cluster including 'Investment in Training' and 'Supplier Development' focuses on learning processes. The second main cluster is related to integration headed by 'Can Handle Cultural Differences' reflecting the movement of manufacturing to the third world in particular to firms in BRIC countries. Other characteristics include 'Transparent Organization', 'High Level of Planning and Control' and 'High Level of Integration in Chain'.

7.4.3.2 First order sum and pair-wise combined – 2nd tier – data set 17

This combination of first order sum and pair-wise data produces two main clusters. The most important inter-firm characteristics are 'Explorative Learning Practices' and 'Formal Partnership'. These are in the same sub-cluster as 'Lean Practice'. The second sub-cluster in the same cluster contains 'Supplier Development' and 'TQM procedures' together with a 'Culture of Continuous Improvement'. The second cluster found in this data set, places 'Outsource Easily Imitable' together with 'High Level Collaboration' and 'High Level of Planning and Control. In this second cluster, a less important sub-cluster exists, containing ‘Easy Dialogue with Supplier’ and ‘Long Term Relations’.

7.4.3.3 Pair-wise – 2nd tier – data set 21

Two main clusters are formed. The first main cluster has two sub-clusters. The first brings together functions to enable continuous improvement, including ‘Supplier Development’, ‘Monitoring Supplier’ and ‘TQM Procedures’. The second sub-cluster is similarly interested in learning including ‘Explorative Learning Practices’ but also more formality by way of ‘Formal Partnership’ and ‘Lean Practice’. The most significant factors are ‘Explorative Learning Practice’ and ‘Formal Partnership’ at tier 2. The second main cluster is concerned with strategic partnership, including ‘High Level Collaboration’, ‘Outsource The Easily Imitable’, ‘Long Term Relations’ and ‘Easy Dialogue With Supplier’. Note how outsourcing is connected with long term relations and collaboration.

7.4.3.4 Analysis of 2nd tier - survey

There are two groups of inter-firm characteristics which are common to each of the data sets described above. The first is related to learning, partnerships and lean methods. Inter-firm characteristics which are key include: ‘Explorative Learning Practices’ and ‘Formal Partnership’ and ‘Lean Practice’. Also in this group are ‘Investment in Training’ and ‘Supplier Development’.

The second group bring together long-term relationships, standardisation and quality management, outsourcing commodity manufacture. The dominant inter-firm characteristics in this group are ‘Outsource Easily Imitable’ and ‘Long Term Relations’. Other relevant characteristics include ‘TQM Procedures’ and ‘High Level Collaboration’.

Integration in the case study of the 2nd tier firm was dominated by the use of lean practices. Innovation in process technologies highlights the need for the first group of characteristics, including explorative learning practices and partnerships, together with methods to raise supplier capability. This is an important dynamic between the 2nd tier and its suppliers, focusing on learning.

Standardisation, particularly the ability to create box builds using standard components via outsourcing such activity, and the use of TQM procedures and long-term relationships to achieve delivery performance in the coevolution of the supply network and the 2nd tier firm, are related to the second group of inter-firm characteristics found in the survey.

7.4.3.5 Summary

This section presented the results of the questionnaire survey which were completed by individuals working at second tier firms. Figure 7-15 demonstrates the characteristics which are important for all three methods of data analysis. NOTE: the table shows inverse coefficient of variation, so that the tallest readings are the most significant.

Explorative Learning Practices, Outsource Easily Imitable, Long Term Relations, Formal Partnership and Lean Practice are the key inter-firm characteristics represented in each data scenario of 2nd tier firms.

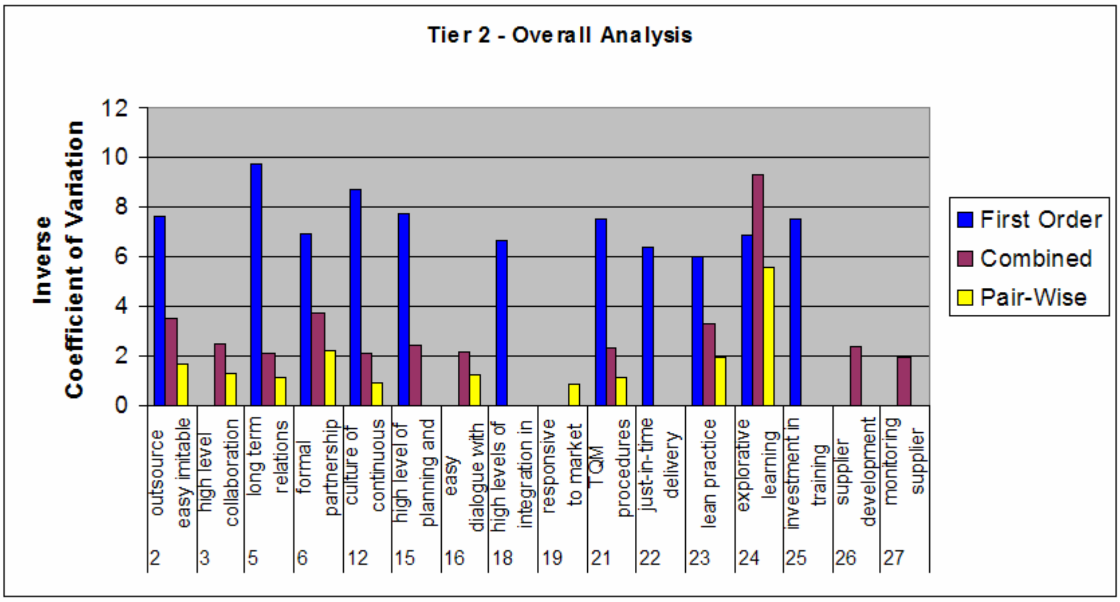

Figure 7-15 2nd tier Significant Inter-Firm Characteristics

7.5 Survey Results for Commercial Aerospace Manufacturing

7.5.1 Performance of all firms

This section presents survey results for all firms in the Supply Network. Three scenarios are considered: First Order data (Table 1) which is data set 9, Combined First Order and Pair-Wise data (Tables 1 and 2), data set 18, and Pair-Wise data only (Table 2) which is data set 22. There is a cross-reference to previous survey results and to Chapter 6 case study results. All cases are included. Detailed dendrograms and charts are included in Appendix N. The final sub-section describes the nature of the commercial aerospace manufacturing industry.

7.5.1.1 First order sum – all firms – Data Set 9

This data set includes all cases. The weighted sum of all performances from Table 1 is normalized and clustered using Ward's Method. The characteristics of most significance are 'High Level of Planning & Control' and 'High Level Collaboration' both in the same cluster. In the same sub-cluster as 'High Level of Planning & Control' are 'Flexible Operations', 'Responsive to Market Change' and 'Can Handle Cultural Differences', bringing flexibility to planning and control. With 'High Level Collaboration' are 'Investment in Training' and 'Supplier Development', identifying the importance of learning and development.

In the second cluster are 'Lean Practice', 'Formal Partnership' and 'TQM Procedures' along with 'Sharing Knowledge'. These bundles of inter-firm characteristics bring together formality of partnership and long-term relations, with quality and waste reduction in a setting of sharing knowledge.

7.5.1.2 First order sum and pair-wise combined – all firms – data set 18

Taking both first order and pair-wise results, we find two clusters of inter-firm characteristics. The highest performing characteristics are 'Lean Practice' and 'Formal Partnership' which are in the same sub-cluster as 'TQM Procedures'. In the same cluster is a second sub-cluster containing the third highest performing practice

‘High Level Collaboration’, which clusters with ‘Easy Dialogue with Supplier’ and ‘Long Term Relations’. The last sub-cluster in this cluster has ‘Culture of Continuous Improvement’ with ‘Sharing Knowledge’. This high performing cluster is focused on partnership and collaboration/long term relations, improving quality, becoming lean and the benefits of long term relations.

The second cluster has three sub-clusters. ‘Supplier Development’ is the third highest-performing inter-firm characteristic in this data and in a sub-cluster with ‘Explorative Learning Practice’, ‘High Levels of Integration in Chain’, and ‘Investment in Training’. ‘Flexible Operations’ is in a sub-cluster with ‘Responsive to Market Change’, ‘Can Handle Cultural Differences’ and ‘Risk-Sharing’. In the final sub-cluster are ‘Monitoring Supplier and ‘High Level of Planning and Control’ together with ‘Outsource Easily Imitable’. This second cluster is focused on learning, development, flexibility and control.

7.5.1.3 Pair-wise – all firms – data Set 22

This final analysis includes all firms and establishes two main clusters in the pair-wise data. The two significant factors are divided across the two main clusters. ‘Supplier Development’ is clustered with ‘Monitoring Supplier’, ‘Lean Practice’, ‘Explorative Learning Practices’, ‘TQM Procedures’ and ‘Responsive To Market Change’. ‘Formal Partnership’, is clustered with ‘Easy Dialogue with Supplier’, ‘Culture of Continuous Improvement’, ‘High Level Collaboration’, ‘Outsource the Easily Imitable’ and ‘Long Term Relations’. The first main cluster is focused on practices which deliver performance outcomes, such as high quality and high efficiency. The second main cluster is concerned with relationship, dialogue and collaboration.

7.5.1.4 Analysis of all firms – survey

There are three groups of inter-firm characteristics which are common to each of the data sets described above. The first group is related to partnerships, quality management, lean methods and sharing knowledge. This group is particularly concerned with contracts and formal methods to achieve tangible performance outcomes. The presence of sharing knowledge raises the need to know within such formal arrangements.

The second group brings together inter-firm characteristics relating to high level collaboration, long-term relations and supplier development. This raises the importance of learning and development. Also in this group is 'Investment in Training'. This group of inter-firm characteristics is much more focus on investment in relationships and long-term outcomes as a result of learning and development. These are less tangible

The third group focuses on supplier monitoring, flexible operations and responsiveness to market change. Also in this group are a 'High Level of Planning and Control' and 'Outsourcing the Easily Imitable'. This group highlights the need to oversee, plan and control within the supply network creating a flexible operation which is responsive to demand.

In the case studies, we find the Prime has adopted a formal risk-sharing partnership model.

Information sharing has been enabled using ICT and standards, also the case for OEM(A) and OEM(B). Demand fluctuations are a key factor for the Prime in the dynamic in the supply network. Performance of the overall supply network is balancing performance needs across cost, delivery and quality.

A focus on the quality management of suppliers, investment in supplier training and continuous improvement of production is evident in the coevolution of the Prime and the Supply Network. Supplier improvement is also a key focus for OEM(A). OEM(B) is gaining strategic advantage from low-cost labour but recognises that over time supplier skills will increase as they are able to take on high-value work and the OEM can take on higher systems integration work. The 2nd tier supplier is using lean and Kanban techniques in the integration of its supply network. The importance of innovation is critical to all firms in the case studies, whether it is product, service or process innovation.

The importance of managing relationships across the globe is relevant to the Prime, and OEM(B)'s preference for good long-term relationships is closely related to supplier development and improvement. Supplier dialogue is important for innovation in the 2nd tier firm.

The empirical survey results have identified the major aspects of firm and supply network coevolution as bundles of inter-firm characteristics that contribute to the success of the supply network and the firm. These bundles of high performing inter-firm practices for the commercial aerospace industry are measured by combining consistent clusters found in all three data sets (9, 18 and 22) for all cases. In order of performance

Top performing bundle:

- 'Formal Partnership'
- 'TQM Procedures'
- 'Lean Practice'
- 'Sharing Knowledge'

Second performing bundle:

- 'High Level Collaboration'
- 'Long Term Relations'
- 'Supplier Development'
- 'Investment in Training'

Third performing bundle:

- 'Monitoring Supplier'
- 'Flexible Operations'
- 'Responsive To Market Change'
- 'High Level of Planning and Control'
- 'Outsourcing the Easily Imitable'

7.5.1.5 Summary

This section presented the results of the questionnaire survey which were completed by individuals working at all firms and used all data collected. Figure 7-16 demonstrates the characteristics which are important for all three methods of data analysis. NOTE: the table shows inverse coefficient of variation, so that the tallest readings are the most significant.

The consistently highest performing inter-firm practices for all firms and for all performance criteria are ‘Lean Practice’ and ‘Formal Partnership’, followed by ‘High Level Collaboration’ and ‘Long Term Relations’.

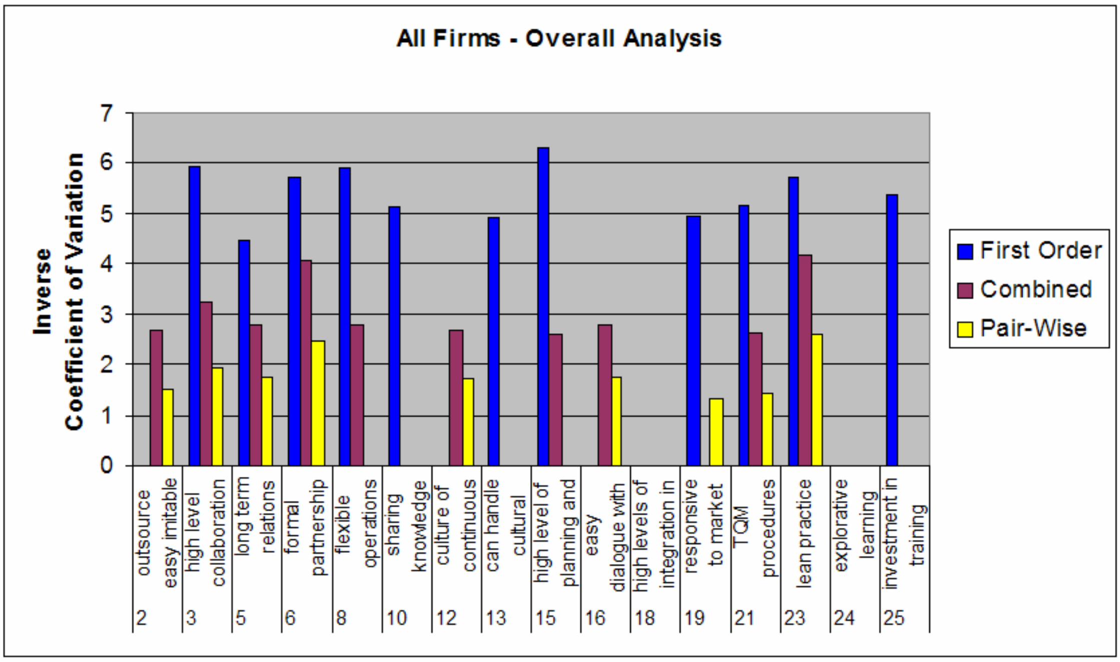

Figure 7-16 All Firms Significant Inter-Firm Characteristics

7.6 Survey Data Statistics

Analyses were carried out on the survey data for two purposes: to detect anomalies in completed questionnaires and to find patterns of similarity across cases. For all Table 1 and Table 2 entries, there were no invalid scores, i.e. scores outside the range of permitted values. In one data set, there were three null cells which were treated as zero scores.

7.6.1 Demographics

Whilst some demographic data was collected this was not provided by all respondents and so is not able to form part of the analysis. Demographic data included the following:

- Maturity of supply network (emerging, mature, and declining) and which attempted to connect to the life-cycle model used in Chapter 2, Figure 2-7)
- Functional unit of respondent (e.g. mechanical, electronic)
- Nature of primary product or system produced by the supply network (e.g. landing system, commodity part).

The primary demographic data used in the analyses is the tier of the firm within the supply network. The primes are Boeing and Airbus for the purposes of this study. 1st tier firms are suppliers to Boeing and Airbus, and 2nd tier firms are suppliers to the 1st tier suppliers. Many 1st and 2nd tier firms are very large in their own right. The tier of each firm is evaluated based on the public information about the firm and the introductions made by the primes to their 1st tier suppliers, and in turn, suppliers to the 1st tier.

7.6.2 First order Table 1 analyses

The percentage frequency of each score (from 0 to 10) from Table 1 of the questionnaire, referred to as First Order data throughout, is analysed by the five performance success criteria in Figure 7-17.

Scores in the range 0-4 account for around 26% of the results except for Technology/Innovation which received around 38%. This indicates that there is less satisfaction with the performance of Technology/Innovation than with any other performance criteria.

For Technology Innovation, a large percentage (12%) of inter-firm characteristics scored 0 indicating no perceived performance in technology innovation in 12% of cases. Highest percentage scores for Cost Efficiency and Delivery Precision was scored 7 at 20.58% and 19.55% respectively. Vision had the highest percentage of 9 scores (the maximum rating) at 14.6% whereas other performances had 9% scoring 9.

	Product Quality		Cost Efficiency		Delivery Precision		Tech Innov		Vision	
	%	cum %	%	cum %	%	cum %	%	cum %	%	cum %
0	9.67	9.67	5.97	5.97	6.17	6.17	12.14	12.14	6.79	6.79
1	0.41	10.08	1.23	7.20	2.47	8.64	3.50	15.64	3.09	9.88
2	5.97	16.05	4.53	11.73	4.53	13.17	6.17	21.81	4.12	13.99
3	4.12	20.16	7.00	18.72	7.00	20.16	7.61	29.42	5.35	19.34
4	7.20	27.37	6.38	25.10	7.20	27.37	8.64	38.07	7.20	26.54
5	13.99	41.36	15.02	40.12	14.61	41.98	13.58	51.65	14.81	41.36
6	16.87	58.23	14.40	54.53	11.32	53.29	10.70	62.35	12.55	53.91
7	16.05	74.28	20.58	75.10	19.55	72.84	16.05	78.40	16.46	70.37
8	16.87	91.15	15.64	90.74	16.87	89.71	13.17	91.56	15.02	85.39
9	8.85	100.00	9.26	100.00	10.29	100.00	8.44	100.00	14.61	100.00
	100.00		100.00		100.00		100.00		100.00	

Figure 7-17 First Order data % frequencies

Some respondents scored the contribution of a characteristic to a performance criterion as zero, indicating that within the firm, the characteristic does not contribute to the performance success of the criteria (e.g. quality). Occasionally a characteristic is scored zero for all performance criteria indicating that the firm does not recognize or has not adopted that characteristic. The use of offsets was commonly scored in this way.

7.6.3 Pair-wise Table 2 analyses

The frequency of each score (from -5 to +5) from Table 2 of the questionnaire, referred to as Pair-wise data throughout, is analysed by the 4 categories of firms: Primes, First Tier, Second Tier and All firms.

7.6.3.1 Primes – pair-wise analysis of ratings

For the Primes, around a third of inter-characteristic effects are 0, meaning that they neither support nor detract from the performance of other characteristics. Around 17% are conflicting to some degree as they score a negative value, although only 2%

are very conflicting scoring -5. Scores are shown in Figure 7-18. The highest frequency non-neutral score is 4, at 17%. 38% of scores are 3, 4 or 5.

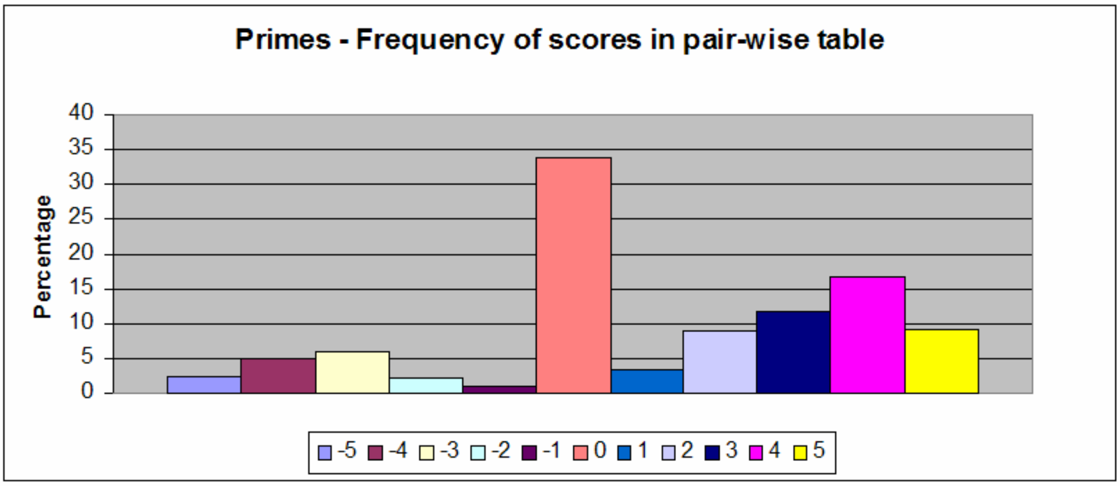

Figure 7-18 Pair-wise data % frequencies for scores – Primes

7.6.3.2 1st tier – pair-wise analysis of ratings

For 1st tier firms, 30% of inter-characteristic effects are 0. Only 4% are seen as conflicting to some degree as they score a negative value, and of this 1.6% are very conflicting scoring -5. The highest frequency non-neutral score is 3, at 21%. 52% of scores are 3, 4 or 5. Scores are shown in Figure 7-19. There appears to be much greater satisfaction of 2nd tier firms (in the eyes of the first tier) than satisfaction of 1st tier firms (in the eyes of the primes).

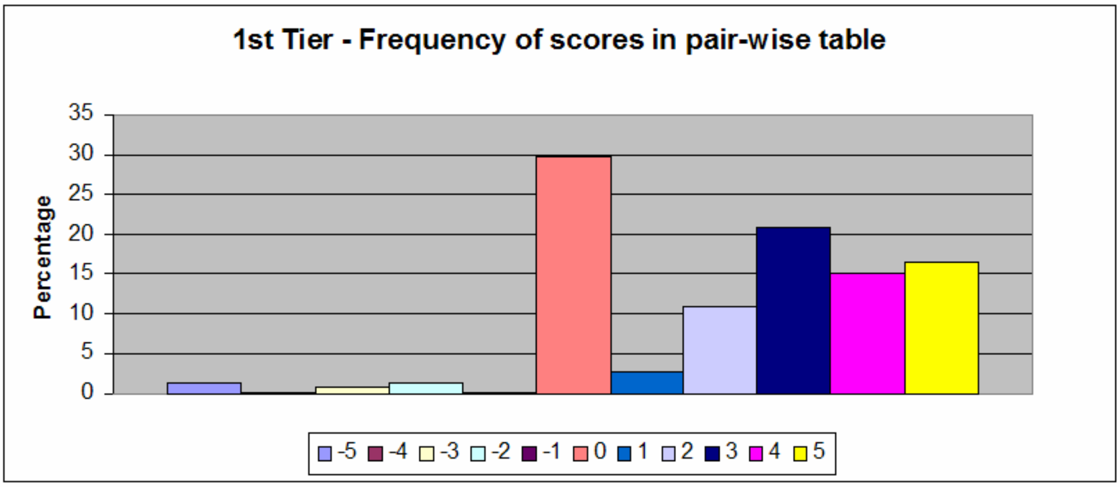

Figure 7-19 Pair-wise data % frequencies for scores – 1st tier

7.6.3.3 2nd tier – pair-wise analysis of ratings

For 2nd tier firms, 16% of inter-characteristic effects are 0. 21% of characteristics are seen as conflicting to some degree as they score a negative value, and of this 1% are very conflicting scoring -5. The highest frequency non-neutral score is 4, at 16% although the spread is fairly even between scores of 1, 2, 3 and 4. Only 37% of scores are 3, 4 or 5. Scores are shown in Figure 7-20. There appears to be much greater conflict in inter-characteristics effects at 2nd tier firms than any other tier of firm.

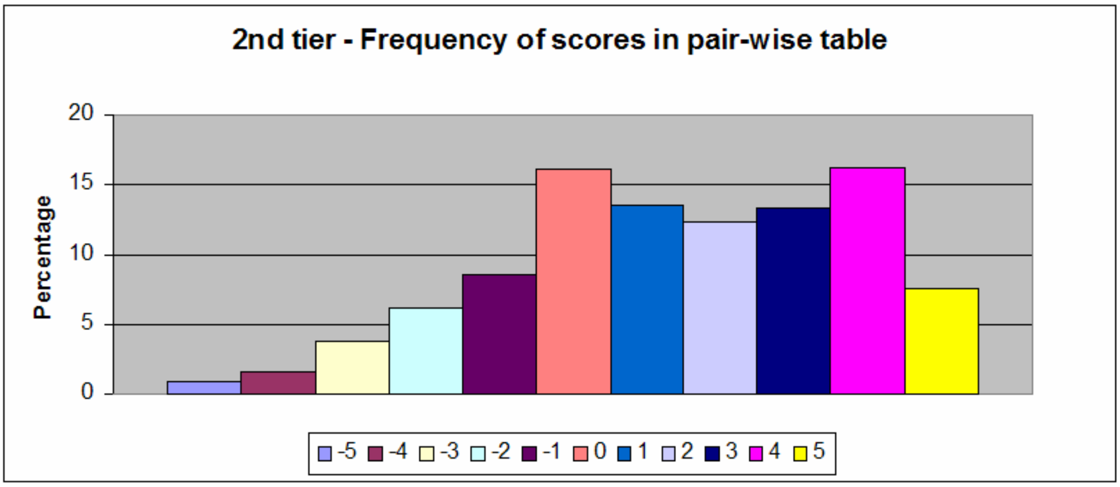

Figure 7-20 Pair-wise data % frequencies for scores – 2nd tier

7.6.3.4 All firms – pair-wise analysis of ratings

The analysis of scores for all firms shows that 24% of inter-characteristic effects are 0. 13.6% of characteristics are seen as conflicting to some degree as they score a negative value, and of this 1.4% are very conflicting scoring -5. The highest frequency non-neutral score is 3, at 16% at score 4 is a close second with just under 16%. 43% of scores are 3, 4 or 5 showing that overall there is a substantial amount of inter-characteristic synergy. Scores are shown in Figure 7-21.

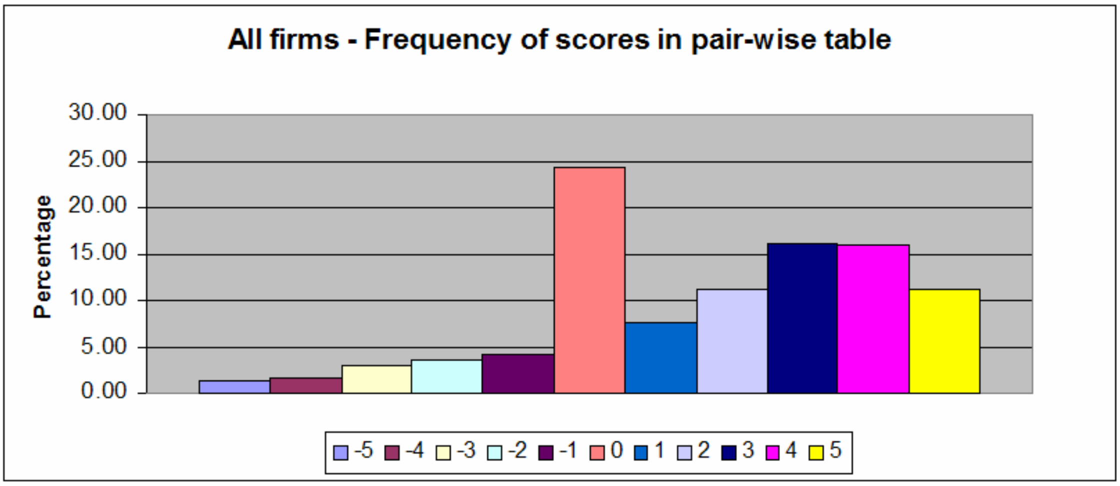

Figure 7-21 Pair-wise data % frequencies for scores – All firms

7.6.3.5 Primes – pair-wise analysis of inter-firm characteristics

This analysis calculates a value for each inter-firm characteristic by adding together the frequency of each score by its score. The analysis of the 27 characteristics shows that for the Primes, characteristic 10 (sharing knowledge) scores most highly with 6.7% of the total score. Characteristic 4 (arms length relations) scores worst with -5% of the score, and characteristic 14 (high level of dominance over supplier) has -4% of the score. No other characteristics have an overall negative effect. See Figure 7-22. Characteristics 11 (offsets as part of sales) and characteristic 15 (high level of planning and control) do not contribute very highly to synergy.

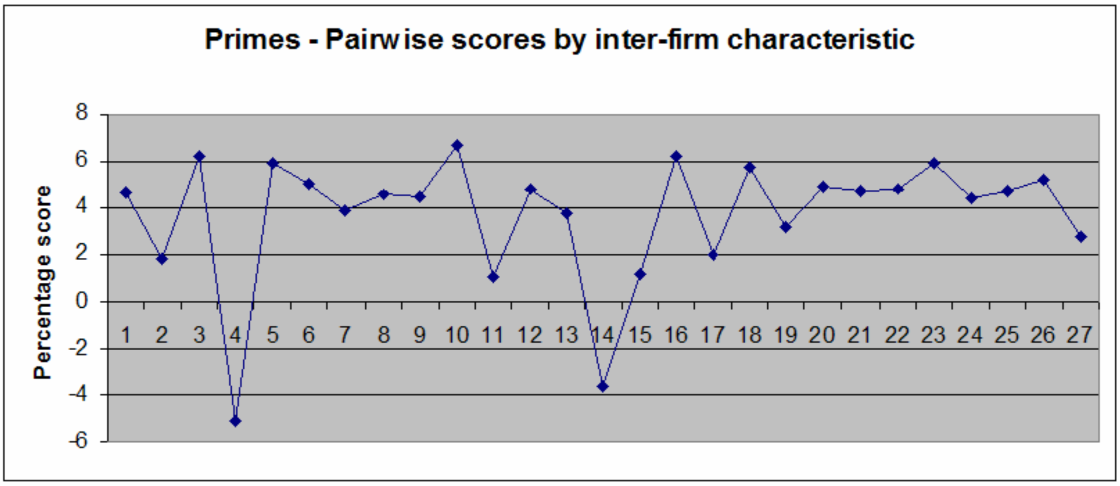

Figure 7-22 Pair-wise data % frequencies for inter-firm characteristics – Primes

7.6.3.6 1st Tier – pair-wise analysis of inter-firm characteristics

The analysis of the 27 characteristics for 1st tier firms shows that characteristic 5 (long term relations) scores most highly with 5.2% of the total score. Characteristic 16 (easy dialogue with supplier) and characteristic 26 (supplier development) score highly with 4.9%. Characteristic 4 (arms length relations) scores worst with 0.5% of the score, and characteristic 14 (high level of dominance over supplier) has 1.1% of the score. Characteristic 11 (offsets as part of sales) is also not very synergetic (2.2%). See Figure 7-23.

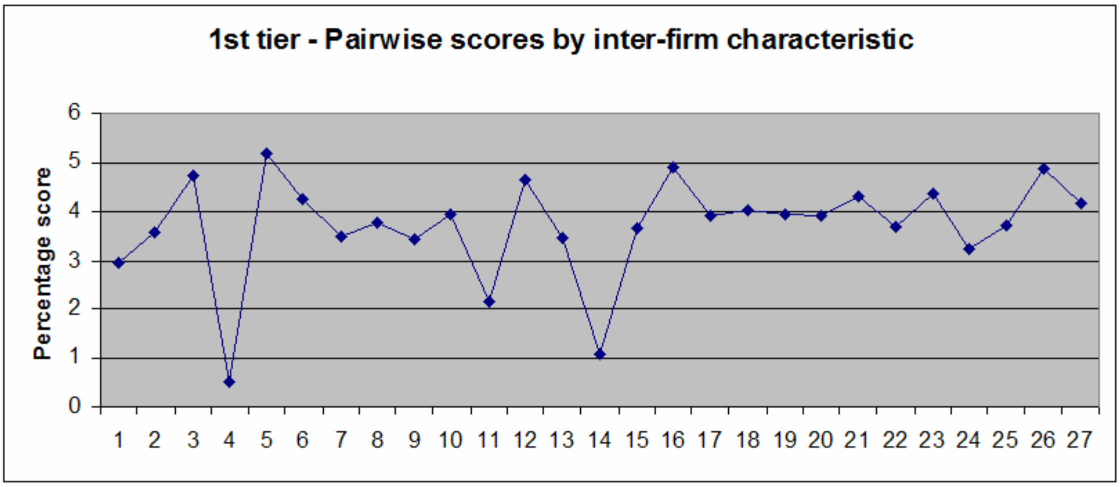

Figure 7-23 Pair-wise data % frequencies for inter-firm characteristics – 1st tier firms

7.6.3.7 2nd Tier – pair-wise analysis of inter-firm characteristics

The analysis of the 27 characteristics for 2nd tier firms shows that characteristic 23 (lean practice) scores most highly with 5.7% of the total score. Characteristic 5 (long term relations) also scores highly with 5.4%. Characteristic 4 (arms length relations) scores worst with -1.6% of the score. Characteristic 11 (offsets as part of sales) and characteristic 14 (high level of dominance over supplier) are also not very synergetic scoring 0.9% and 1.8% respectively. See Figure 7-24.

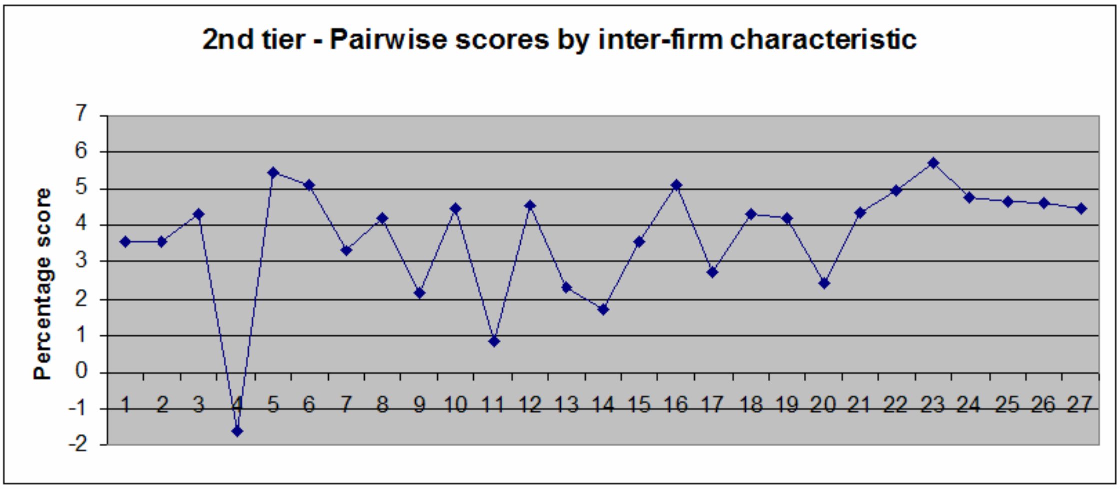

Figure 7-24 Pair-wise data % frequencies for inter-firm characteristics – 2nd tier firms

7.6.3.8 All firms – pair-wise analysis of inter-firm characteristics

The analysis of the 27 characteristics for all firms shows that characteristic 5 (long term relations) with 5.4% is the most synergetic of all characteristics, closely followed by characteristic 16 (easy dialogue with supplier) with 5.1% and characteristic 23 (lean practice) with 5% of the scores. Characteristic 4 (arms length relations) is the only conflicting characteristic, scoring -0.9%, and characteristics 14 (high level of dominance over supplier) and 11 (offsets as part of sales) are low scoring with 0.8% and 1.5% respectively. See Figure 7-25.

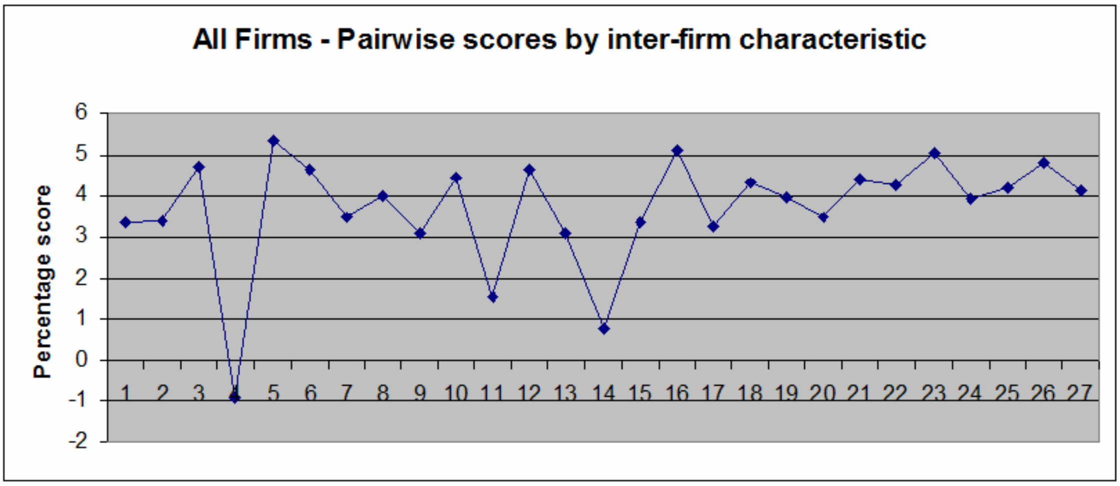

Figure 7-25 Pair-wise data % frequencies for inter-firm characteristics – All firms

7.7 Closing Remarks

This chapter presented the analyses of the survey data, which have presented results using sub-sets of the data: by performance criterion, by tier of firm, and overall for the whole industry. Data was also combined in novel ways from Tables 1 and 2, first order and pair-wise data respectively, in order to present a more informed analysis.

The overall analysis of the results finds that there are three bundles of characteristics which are evident regardless of the data set examined. These are:

Top performing bundle:

- ‘Formal Partnership’
- ‘TQM Procedures’
- ‘Lean Practice’
- ‘Sharing Knowledge’

Second performing bundle:

- ‘High Level Collaboration’
- ‘Long Term Relations’
- ‘Supplier Development’
- ‘Investment in Training’

Third performing bundle:

- ‘Monitoring Supplier’
- ‘Flexible Operations’
- ‘Responsive To Market Change’
- ‘High Level of Planning and Control’
- ‘Outsourcing the Easily Imitable’

The distribution of scores by performance criteria and by inter-firm characteristic are also presented. These identify the high and low scoring areas and the tendency for respondents to score highly.

This thesis has now answered two of the questions posed for Phase 3 of the research: Q3a: "*What are the performance trade-offs in inter-organizational characteristics*?" and Q3b: "*What differences are there in inter-organizational characteristics at different tiers of the supplier network*?". For the third question Q3c: "*How do supply chain dynamics relate to supply network structure*?", this is discussed in Chapter 8 as this is the crux of the thesis.

The next and final chapter discusses the results of the empirical studies by reflecting on the literature. It states the contribution of this research, proposing areas for further research and so examines the limitations of this contribution.

8 CONCLUSIONS AND REFLECTIONS

"(I)t is innovation, evolution, and competition which are the hallmarks of a successful system. This is a fundamental message from Hayek and Schumpeter which shines to us across the decades."

(Ormerod, 2005: 228)

This chapter draws together the literature and empirical studies, identifying points on which there is agreement and those which are less clear. The results from Chapter 2 which identified trends in the environment of commercial aerospace have been affirmed by the case studies and survey results: global connectedness, technology know-how, customer expectations (e.g. quality, cost), competition and 'sustainability, regulations and legislation'. Chapter 3 findings are incorporated into the survey questionnaire and research design. The literature reviewed in Chapter 4 is examined in light of empirical results.

Chapter 8 is organized as follows. The first three sections look at Evolutionary Theory, Coevolutionary Theory, and Complex Adaptive Systems. The coevolutionary conceptual framework developed in chapter 4 is extended in the fourth chapter, based on the results of both the case studies and the questionnaire survey, and the analysis of the literature. The conceptual framework is thus contextualized within the global commercial aerospace manufacturing sector and its revision is presented in section 4. Section 5 states the contributions and limitations. Section 6 proposes opportunities for further research and the final section provides closing remarks.

8.1 Evolution

This section reviews the literature in Chapter 4, Section 1 on evolution and where possible, provides empirical evidence to support, extend or question the relevance of the literature to the coevolution of the firm and the supply network in the commercial aerospace manufacturing sector. There are three parts to this sub-section. The first looks at the applicability of inheritance systems. The second examines evolutionary transitions. The last looks at the literature on the evolution of firms.

8.1.1 Inheritance systems

The dominant notion in evolutionary theory is that of inheritance and of the DNA sequence being the only unit of heredity, that is, acquired characteristics are not inherited. DNA is passed to offspring in the process of reproduction or multiplication. Offspring are unique but similar to ancestors. And in order for evolution by natural selection to occur, there must be competition, which affects survival and multiplication rates, apparently influencing evolution in a way that will favour the survival of the fittest.

The firms in aerospace manufacturing are formed from all the objects (such as people, assets, resources) in the system and their interactions. This is the internal diversity of the system creating a complex web that underlies innovation and production. If and when the internal diversity changes, for example, new people, assets, etc are acquired, the system may evolve. However, a change in internal diversity may not cause an evolutionary change, particularly if the new objects or interactions are just 'more of the same' as the firm has already. The proportion of these objects will be greater within the firm and possibly within the environment if they have come from outside the system. We conjecture that it is the addition of internal diversity which is different from current internal diversity that might cause an evolutionary surge. Critically, this new internal diversity needs to adhere and 'invade' the current internal diversity. And the internal diversity incorporates the information or instructions corresponding either to some new operation or to the performance of an existing operation in a new way. This accords with the view of Cladistics. In Cladistics, new characteristics revise the organizational form only if they survive as qualitatively different from the previously perceived internal diversity. Higher rates of innovation are found in organic firms although radical change is unlikely as the strategy of incrementalism tends to delimit radical change (Hage, 1980).

We might look at this from the point of view of mergers and acquisitions. Many of the behemoths of the aerospace industry have been created in this way (for example, Convair and its route into Boeing, via McDonnell Douglas (US Centennial of Flight Commission, 2003) or BAE Systems (BAE Systems, 2005) demonstrating its heritage of British Aerospace and Marconi Electronic Systems, each the product of other mergers.

The loss of internal diversity for example by de-merger, spin-out, and other less public means, is also a potential for the evolution or regression of firm internal diversity. For firms, internal diversity is always in a state of flux largely because of the movement of people between firms. So when there is a loss of some part of the internal diversity because it is retired or diminished, then the characteristic it contributed is removed on a Cladogram, in a similar way to the addition of characteristics which cause a new clave to appear.

The final aspect on internal diversity is the revision of objects already in the system. Objects such as buildings and machinery do not themselves evolve, but their use changes over time or they are replaced by more modern varieties which have new or improved features. Similarly, resources do not evolve, but innovations, for example, composite materials, are developed or appear in the market place and become a resource to the firm and enhance its internal diversity. Interactions evolve for example as the underlying infrastructure evolves, such as new and improved networks or telecommunications devices. People learn and acquire new skills, capabilities, and processes to exploit other parts of the changed internal diversity of the firm.

Competition in the market place for the firm's products and services means that there is natural selection as a result of which one firm may grow faster than others, increasing its proportion of internal diversity in the pool. It is not altogether clear that the fittest survives in the commercial aerospace industry. For many years national governments protected their firms (see Chapter 2, Section 4) but nowadays global competition exists.

The notion of inheritance, and so the notion of the firm (and the supply network) having internal diversity, and processes of growth, replication/multiplication and survival, are all relevant to socio-economic systems. There are however six important points to make here which are different for socio-economic systems.

First is that the internal diversity of a firm (and supply network) may be described by other researchers using different characteristics along different dimensions; it is not absolute in the way that biological DNA has 23 pairs of chromosomes. Whilst I have found particular characteristics of interest, other studies may legitimately find others. In a similar way, the phenotype (or form) of a firm or supply network, may be perceived differently by others. Whilst I have presented a Cladogram of the supply network forms in the commercial aerospace supply network, other researchers may find different supply network forms. There is no absolute truth in this. All we might hope for is a close consensus, and absolute fact, should it ever arise, may only be the case after the demise of the industry and once the terminology we use to describe characteristics and forms is no longer evolving.

Second is that we are able to achieve the same macro outcomes with different combinations of characteristics. This may be because macro order has much less variety than micro diversity might suggest and so different combinations of micro-diversity must therefore converge to the same macro order. This also brings in the importance of epigenetic inheritance (see Chapter 4 section 1), in which future structure is influenced by current structure, possibly more so than by changes in internal diversity.

Third is time. The time-span of an industry, if classed as a species, may survive, evolve and expire in a very short relative time. Commercial aerospace manufacturing of jetliners in their current form started only in 1943 and the earliest commercial (single seat) plane was produced in 1849 (see Chapter 2, Section 1), so the first firms in this species are around 170 years old (allowing around 11 years for the firm to be in place without a producing a airplane). Modern humans originated about 200,000 years ago based on DNA evidence and yet we have 95% concurrent DNA with chimpanzees who were around 5 million years ago (Britten, 2002).

Fourth is the constancy of internal diversity. Individuals retain the same DNA throughout their lives. A firm's and a supply network's internal diversity is in a constant state of flux largely because of people turnover. Whilst we might find alternative ways to describe the characteristics of a firm and therefore we can find firms which have the same organizational form because they have similar characteristics, each firm (and supply network) is undoubtedly unique using the definitions above, since people, the productive services available to a firm for expansion are heterogeneous and unique to each firm. They are not reducible to any common denominator (Penrose, 1959).

Fifth is the importance of inheritance systems other than internal diversity. Acquired characteristics, for example, such as those obtained by acquisition or partnership, play a significant role in the evolution of the firm (and the supply network). There is no doubt as to the importance of founding internal diversity constituted in the individuals who establish these firms such as William E. Boeing (Boeing Website, 2009) however as new internal diversity is added, the firm grows or multiplies in the population, and it is this new internal diversity, if integrated into the firm, that may constitute the evolution of the firm (and supply network).

Jablonka and Lamb (2005) raise the importance of 2 further inheritance system (in addition to DNA inheritance and epigenetic inheritance). Behavioural inheritance, such as ‘Explorative Learning Practices’, is particularly importance for Technology Innovation (see Chapter 7 section 3) and for Tier 2 firms (section 4). Symbolic inheritance relating to cognition, communication, language and other types of symbol is evident in the globalization of the supply network and the need to ‘Handle Cultural Differences’.

Last is that variety creation is both teleological and stochastic, confirming that internal diversity inheritance is not the only means to evolution in firms and supply networks. Firms aim to influence their own evolution, seeking to establish a future by adopting characteristics and performance criteria today which act as a trade-off between profits today and a future tomorrow.

8.1.2 Evolutionary transitions

Maynard Smith and Szathmáry (1995) in their study of evolutionary transitions, looked at the common properties of transitions. We find that the evolution of firms is in agreement with their 5 properties. Historically, smaller firms have come together to form larger firms. The differentiation of smaller entities in the larger entity can occur in one of two ways: business/sub-unit or product/service. In the case study of OEM(A) acquired businesses had been left alone, and so were differentiated from the owning firm by business but as part of the supply chain centralization process rationalization of the businesses meant that the production of products and services became differentiated. The replication of the smaller entities is possible usually only via the larger entity because these now belong to the owning firm and do not exist in their own right. Smaller entities can disrupt the development of the larger entity, for example, the production issues related to the new jetliner model A380 at EADS (Heinen, 2006). Firms arise and evolve because new ways are found to store, transmit and interpret information.

In addition to these five properties, the empirical results point very strongly towards systematization or modularization as the products produced become more complex. This is essentially a simplification of an increasingly complex demand upon the firm. It may be possible to extend the properties by adding a further property, such as
6. The larger entity simplifies complexity by a process of modularization.

8.1.3 Evolution of firms

This subsection discusses conclusions from the literature on the application of evolutionary theory to firms (see Chapter 4 section 1). The summary of conclusions is reproduced:

1. Structures move from simple, undifferentiated, homogeneity to a complex, differentiated, heterogeneity, while being accompanied by a process of greater integration of the differentiated parts.

2. Evolution is dynamic
3. Firms have routines not genes
4. Firms tend to become isomorphic with their environments
5. Interactions between firms and their environments influence the ability of the firm to exploit and explore
6. Selection processes do not always drive out the least ‘fit’ firms
7. Mechanisms must exist to create variants of existing structures
8. Selection in the environment runs at a slower rate than the rate at which new variants are created
9. Retention mechanisms must exist to pass on existing variants to new structures

This research on the coevolution of the firm and the supply network has not examined all of these conclusions. Point 1 is consistent with the Cladistics approach (see Figure 3-9). On point 2, one of the dimensions in the conceptual coevolutionary framework was the dynamics between the two entities. Certainly, evolution has a non-stop dynamic even though the qualitative, observable evidence of evolution is punctuated with apparently long static intervals between.

Rather than routines, we have described the internal diversity of the firm as the objects (such as people, assets, and resources) and their interactions. These are broader than routines and so encompass the broader aspects of people that do routines, the buildings and machinery which enable the routines to be carried out, and also the resources that are transformed as part of the routines. In the survey study of coevolution of the firm and the supply network we have looked at inter-firm characteristics which describe structural, integration and dynamical interactions.

The environment of commercial aerospace manufacturing is defined in Chapter 2. For commercial aerospace manufacturing, point 5 is usefully extended to include products, so “Interactions between firms and *their products with* their environments influence the ability of the firm to exploit and explore”. Jetliners have advantages connecting people and nations, demands in terms of infrastructure (airports, road and rail connections), negative environmental effects (emissions, noise, severe accidents) and demand for innovation stimulated by new technologies.

Point 6 appears to be less relevant. We have already noted the national protectionism which will have saved less fit firms in the past, and how this is changing to global competition. On the other hand, we find this industrial sector dominated by two giants, so if either fails, we are left with a monopoly which will have no competition and no drive to innovate or to evolve. The growth of airframe manufacturers in Russia and China are currently the only potential future sources of competition.

8.1.4 Summary

This section extended the literature on evolution into the domain of coevolution of the firm and the supply network in the commercial aerospace manufacturing sector. A summary of findings are:

1. Genetic, epigenetic, behavioural and symbolic inheritance systems operate in firms.
2. The internal diversity of the firm cannot be defined absolutely and may be interpreted by others in different ways.
3. The same macro outcomes can be achieved in multiple ways from the micro-diversity within
4. The evolution rate of socio-economic systems is very fast compared to biological evolution
5. A firm's internal diversity is in constant flux
6. Variety in the population is created both purposefully and without purpose.
7. The larger entity (firm or supply network) simplifies complexity by a process of modularization
8. Although coevolution is a non-stop dynamic, qualitative observable evidence of evolution is punctuated with apparently long static intervals between.
9. Interactions between firms and *their products with* their environments influence the ability of the firm to exploit and explore

The next section reviews coevolutionary theory.

8.2 Coevolution

This section reviews the literature in Chapter 4, Section 2 on coevolution and where possible, provides empirical evidence to support, extend or question the relevance of the literature to the coevolution of the firm and the supply network in the commercial aerospace manufacturing sector.

Five main reasons are given for the adoption of a coevolutionary perspective:

1. increased global competition extending the selection environment of the firm
2. the dynamics of firms, markets and economic systems such that competitive advantage cannot be fixed
3. the firm is nested within other systems and is itself an entity formed from other systems meaning that it is connected with others at all levels, and involves both competition and cooperation
4. investment is needed by the firm in innovation as experimentation is critical to its competitive position
5. strategic management provides a mechanism to help shape the future of the firm

These reasons are examined in light of the empirical evidence in the remainder of this sub-section.

8.2.1 Global competition

Global competition is pervasive throughout the case studies. It is perceived as an opportunity to supply globally and to source globally.

The Prime in the case study notes that the loyalty of airlines to home country manufacturers has changed over the last 30 years. Nowadays, there is global competition for local customer business. The Prime has had to lose some of its arrogance and evaluate the reasons for customers choosing to buy elsewhere, and although this has been difficult to learn but is now embedded in the firm.

For OEM(A) in the case study a national study had noted that it was perceived by the industry as not very competitive. Customer "*price-downs*" (i.e. the Primes paying less to 1st tier suppliers) had led to the search for suppliers in low cost economies which are locations that OEM(A)'s competitors have already started to exploit. Access to global markets is perceived as mandatory to maintain status as 1st tier supplier to the Primes.

For OEM(B), manufacturing in low-cost economies is used as a strategy to reduce cost. Quality is mandated and whilst delivery is very important in order to reduce the time to put new products into production, it is cost which is driving competitive advantage. Future jetliners pricing is reducing so much that it is already near to the cost of the raw materials, before any processing. It is driving the use of low-cost economies as western firms simply can't compete on manufacturing cost of high-volume commodity parts.

For the 2nd tier supplier seeking consistent performance from its suppliers means a focus on time, cost, quality and agility, and these demands upon suppliers are increasing as there is more competition available globally.

8.2.2 Competitive advantage

Cutting costs is perceived as the main driver to achieve competitive advantage. In the case studies, the main method to cut costs for the Prime was via risk-sharing partnerships, whereas for the OEMs and the 2nd tier firm, it was the availability of cheap labour in low cost economies, so that globalization has become a strategy for cost reduction.

'Outsourcing Competitive Advantage' was an inter-firm characteristic found to be important in the survey of the primes. It was clustered with 'Sharing Knowledge', 'Long Term Relations', 'TQM Procedures' and 'Culture of Continuous Improvement'. This notion that competitive advantage is transferred to the 1st tier firms is balanced by the introduction of risk-sharing partnerships. These partnerships are implemented via programmes and related contracts which enable the Primes to be explicit about what must be done to supply a product, including the activities that must be achieved by the firm's suppliers. Suppliers benefit from owning Intellectual Property Rights (IPR) of the outsourced system, which means that if something goes wrong with the airframe, then the supplier is accountable for their part. All this shows us that in these co-evolved systems the interactions between firms involves both competitive and cooperative forces.

8.2.3 Nested systems

From the case studies, we find that as part of innovating, the Prime is beginning to think about the future from the supply network perspective. It is an opportunity to improve network performance by evolving the current supply network into one fit for the future. Experimentation is part of the collaboration process in the attempt to find the right mix of suppliers for supply network evolution.

For OEM(A) in the case study, a national study noted that it was perceived by the industry as not very competitive. A restructuring and centralization of supply network management was implemented in an approach which recognized that competition was no longer between firms; "*it is supply chain against supply chain, and a loosely connected supply chain is no competition against a fully integrated one*." (cited from transcript) The firms and the integration between the firms in the supply network, is perceived as an entity which provides competitive advantage.

The supply network has become an extension to the firm, providing resources and skills that the firm lacks, allowing it to concentrate of its core capabilities. Firms have become more specialist and less diverse, and with these specialisms are now producing products and services for a wider range of customers.

8.2.4 Innovation and competition

The case study of the three largest firms in aerospace manufacturing (Varga and Allen, 2006) used an innovation framework (Adams, 2003) to classify innovations at each firm (reported on within their Annual Reports) into one of three types based on their characteristics. This analysis of innovations contributes to describing the evolutionary potential of the firm.

One of the four core categories in the case study of the prime, was innovation. The core category included: continuous improvement in the manufacturing processes; R&D collaboration with suppliers creating 'blurred technology' targeted in ways to benefit both the Prime and the supplier; experimentation in the supply network; technological leadership balanced with risk management; and innovation in product services post delivery.

Innovation at OEM(A) is customer-led. It focuses on innovation in engineering designs. Competition from cheaper suppliers innovating in maintenance and repair, means that OEM(A) may suffer from lack of innovation in this area. The systematization of jetliner production has raised the bar for many first tier suppliers like OEM(B) now producing a number of integrated systems. Integration work previously carried out by the prime has moved to the 1st tier. The role of the systems integrator is seen as a competitive position of engineering and integration expertise. For the second tier firm, process technologies are becoming a focus to provide competitive edge. Competitive suppliers are bringing in lower costs and innovation to the supply chain.

Technology innovation was one of the five performance success criteria in the survey. Inter-firm characteristics making a high contribution to technology innovation performance are 'Investment in Training', 'Explorative Learning Practices', 'Culture of Continuous Improvement', 'Easy Dialogue with Supplier', 'High Level Collaboration' and 'Long Term Relations'.

In a comparative study (Nelson, 1993) national innovation systems were found to reflect differences in the priorities and circumstances of the economies and political circumstances. Size and the level of affluence was a major differentiator favouring strong national innovation systems. Strong defence programmes and so R&D investment explained smaller size countries having large national innovation systems.

8.2.5 Future shaping

A number of strategies for shaping the future are evident in the case studies.

Services are perceived as an area of opportunity at the Prime. '*Life-cycle product teams*' are in place because in the future, more business is expected to arise after the delivery of jetliners than it does today. The Prime will have less and less manufacturing and assembly and so the aspiration is to product services.

The Prime is helping to shape markets in countries which are likely to buy large numbers of jetliners in the future. Relationships need to be developed with industrial bodies and firms, developing skills and building the infrastructure needed to run an economy that has regular air travel.

For OEM(B), it is understood that services, such as flight hours, will be sold rather than jetliners. There will need to be refocusing on product maintenance and repair, and the design and engineering of long-lived components, in order to extract profitability over the product life-time. It is expected that primes will mandate *"a level of in-country content"* in their contracts with OEM(B) because the primes themselves will be selling most jetliners into these LCE countries. Whilst these contracts will relate only to jetliners destined for the same country, it is likely that next generation jetliners will use the same manufacturing and assembly plants.

SecondT, the 2nd tier supplier in the case study, anticipates that there will be an increase in box-builds and electronic assemblies, each of which is customized. Standardized components will be used to create this variety.

Vision for the future was one of the five performance success criteria in the survey. Inter-firm characteristics making a high contribution to vision performance are 'Long Term Relations', 'High Level Collaboration', 'Investment in Training', 'Culture of Continuous Improvement', 'Easy Dialogue with Supplier', 'Formal Partnership', 'Lean Practice and 'TQM Procedures'.

8.2.6 Novel aspect of coevolution

In addition to supporting the five reasons for the use of coevolutionary theory, the empirical studies suggest a further aspect of coevolution related to learning and training.

The learning and training available in the supply network, particularly in order to increase quality and delivery performance in the process of continuous improvement, but also in the process of innovation with customers and suppliers, allows the firm to increase its skills and knowledge, which has the potential to improve the performance of the supply network, in a coevolutionary way.

As suppliers learn how to act in a way that is higher performing and to innovate via integration with other firms in the supply network, they are more likely to add greater value to the supply networks. As the supply network increases its skills and knowledge, it will also be more able to compete with other supply networks. The drivers to learn more include raised competition, higher product complexity of the jetliners and increasing quality and delivery standards.

8.2.7 Summary

This section provided support for the adoption of coevolutionary theory and identified a novel contribution from commercial aerospace manufacturing. The novel contribution was the role of learning and training in the coevolution of the firm and the supply network. Specific contributions from firm and supply network coevolution in commercial aerospace manufacturing are made to each of the 5 extant aspects of coevolution.

The next section reviews the complex adaptive systems perspective used in this thesis.

8.3 Complex Adaptive Systems

This section reviews the literature in Chapter 4, Section 3 on complex adaptive systems and where possible, provides empirical evidence to support, extend or question the relevance of the literature to the coevolution of the firm and the supply network in the commercial aerospace manufacturing sector.

Earlier results demonstrate the dynamics, or flux, evident in supply networks and firms. The particular field of analysis supports the view that these socio-economic systems are changing constantly and organizing themselves without any singular entity deliberately managing them, and that what emerges over time is a coherent form. Dooley's (2002: 5020) definition has been used as a guide to the supply network as a complex interaction of nodes in which the focus of complex systems research is "*the interplay between a system and its environment and the co-evolution of both the system and the environment*". We take the system as the firm and the environment as the supply network as the environment is merely another complex system as every system takes every other system as its environment (Kauffman, 1993).

Sub-sections in this section examine nested systems, novelty and coevolution, adaptation and feedback, emergence and macro order, the firm as a CAS and the supply network as CAS. This mirrors Chapter 4 literature.

8.3.1 Nested systems

At any given level of organization, via a nesting of systems within systems, a complex adaptive system will be composed of lower-level micro-networks and inter-woven systems which are in turn embedded into a higher-level macrostructure. This nesting of complex adaptive systems means that complex adaptive systems can aggregate in multiple ways to produce an emergent whole, which has a structure and properties that may be described qualitatively.

From the perspective of this research, there are two points to make regarding the nesting of systems. The first is that even though a system may be reduced to its component parts, such as a firm being reduced to its people, assets, resources, processes and interactions, it is impossible to know what the emergent structure and properties might be beforehand. The second is that the structure and its properties may be described by others in different ways, that is, different valid dimensions may be used as qualitative explanation.

What is essential is a clear definition of what contributes to the complex adaptive system. From the perspective taken in this thesis, the supply network is made up of inter-firm characteristics. Intra-firm entities (people, etc) are perceived as belonging to the firm and not the supply network. Inter-firm characteristics can be grouped into three aspects similar to those identified in the coevolutionary conceptual framework: structure, integration, and coevolutionary dynamics, and used in the case studies and shown in Figure 8-1.

STRUCTURE	1. Outsourcing competitive advantage 2. Outsourcing what is easily imitated 4. Arms length relationship 5. Long-term relationship 6. Formal partnership 7. Subcontracting whole systems and sections
INTEGRATION	11. Offsets as part of sales contract 13. Ability to handle cultural differences 17. IT system integration 18. High levels of integration in chain
COEVOLUTIONARY DYNAMICS	3. High level of collaborative relationship 8. Flexibility of operations 9. Risk-sharing 10. Sharing knowledge 12. Culture of continuous improvement 14. High level of dominance over supplier 15. High level of planning and control 16. Easy dialogue with supplier 19. Responsive to market change 20. Transparent organisation 21. TQM procedures 22. Just-in-time delivery 23. Lean practices 24. Explorative learning practices 25. Investment in training 26. Supplier development 27. Monitoring suppliers

Figure 8-1 Classification of Inter-firm Characteristics

Whilst a classification is helpful, it assumes uniformity which is unlikely to be the case as we note in the case studies. Each firm's relationship with a supply network, that is, to specific other firms in the supply network, is unique, dynamic and coevolving. Whilst firms are nested in one or more supply networks, their membership of the supply network is idiosyncratic. And as Holland (Holland, 1998) reminds us, the activities of the parts do not add to give the activity of the whole. It does not follow that more activity from one part contributes to greater activity of the whole, as it is the product of coupled and context-dependent interactions of the parts that gives rise to emergence at the whole.

This sub-section notes that extant inter-firm characteristics are achieving a particular level of performance. Complex Systems knowledge tells us that we cannot know or reduce the performance of the whole to the sum of its parts.

8.3.2 Novelty and coevolution

Coevolution occurs when the direct or indirect interaction of two or more evolving units produces an evolutionary response in each (Van Valen, 1983). Each complex adaptive system attains a niche provided by the mutually accommodative coevolutionary adaptations of other complex adaptive systems. In this research we have found many examples of mutual accommodation: the Prime in the case study, by choosing to partner, rather than to vertically integrate, allowed new complex adaptive systems to emerge creating different forms of competition; the prime, driven by increasing product complexity, choosing to outsource systems rather than components driving adaptations in the supply network which favoured systems integrators; OEM(A) centralizing and rationalizing suppliers thus generating consolidation in the supply network and new opportunities; OEM(B) seeking strategic advantages of cost efficiency by replacing suppliers with those in LCEs thus changing the diversity of the supply network, creating new challenges and opportunities; SecondT and OEMs increasing specialization creating customized products for new customers and new market niches, extending the supply network.

The Prime's influence on the supply network and its dominance throughout the supply network is a reflection of its desire to continuously reproduces its internal structure without reference to outside sources in the interests of maintaining its essential identity. Both the Cladogram and interviews suggest a homogeneity between Boeing and Airbus, such that the supply networks of each are very similar, albeit one is perhaps more evolved than the other. And of course, they share many of the same suppliers, so it is not surprising that they are similar.

Change and innovation is constant in the firms and supply network, although our results indicate that once established, there is incremental or continuous improvement, rather than radical change. Radical change is implemented into new supply networks, so major innovations occur outside of operational supply networks.

We know from Complex Systems Theory that the past co-produces the present and limits the future states of the system. Importantly, a complex adaptive system exhibits self-transcendence, thus it learns and evolves. Complex adaptive systems operate at a point far from equilibrium and are continuously in a state of flux as energy is imported from the environment and its sub-systems.

8.3.3 Adaptation and feedback

Adaptive evolution of a complex adaptive system occurs as its states are modified in ways to enhance its chances for success (Capra, 1996) via a process of self-organization (Kauffman, 1995a). Each complex adaptive system has the property of self-organization, such that without any explicit co-ordination between its sub-systems, it exhibits emergent forms at the macro level. The empirical studies highlight the demands upon self-organization of dynamic processes in the supply network. There are a number of aspects to this including changes in demand, continuous improvement and learning.

Once established the supply network is subject to changes in demand. Customer demand halved in a three year period then recovered in a three year period witnessed between 2000 and 2008. The effect on suppliers is to diversify into other markets when demand is low. In the case studies, the second tier supplier noted the extra costs attached to meeting short-term increased demand, which were then not passed on to the customer, acting as a negative feedback, keeping profits low and production stretched. The dynamic of supplier improvement for OEM(A)'s suppliers acts as feedback in response to investment in training and supplier development by OEM(A). The Prime observed that high demand growth is a risk to the survival of firms, so we might conclude that self-organization cannot always act quickly enough or that it may be constrained in some way.

Continuous improvement, via quality management, just-in-time delivery processes, lean practices, are the norm within existing commercial aerospace supply networks for all firms in the sample. The top inter-firm characteristic across all three analyses of the survey for the Primes was a culture of continuous improvement. This is perceived as adding the most overall performance to the supply network.

The Prime is investing in the development of skills related to its products, via educational relationships around the world, mitigating the reduction in local engineering graduates, creating knowledge and learning for the future in a positive feedback loop. Innovation in composites is being monitored by the Prime as it is perceived to be a risky investment. Where there are perceived successes, these are nurtured. In the survey, 'Explorative Learning Practices' are particularly important for Technology Innovation. In the overall survey results, the second highest performing bundle, involves supplier development and investment in training, which indicate positive returns to learning within the supply network.

Interactions are non-linear such that small changes cause disproportionately large effects at the observable macro level, so whilst endeavours are made to foster positive feedback, it is only desirable if it is virtuous and not vicious. Adaptations act in a non-linear way and so the firm's adaptations may improve or contract the performance of the firm or the supply network. The firm attempts to improve its own performance but cannot be sure of the effects of its adaptations. The case studies also hint strongly at negative feedback in operational supply networks. The retention of the existing suppliers and minimal change to product specifications are techniques to maintain the status quo, and so act as a form of homeostasis.

8.3.4 Emergence and macro order

The case studies indicate that hierarchic development has occurred in the emergence of the most recent supply network archetype. Hierarchic development involves moving to a higher level where there are greater degrees of structuralisation, differentiation-integration and functional capacity among variables (Taylor, 1976). By the processes of vertical disintegration, differentiation between suppliers via specialization, increased need for integration of systems and higher product complexity, it is suggested that the heterarchic supply network archetype is emerged from the vertically integrated archetype.

In the change from one archetype to another, the supply network will have reached a bifurcation point, in which a bundle of inter-firm characteristics relating to the new form will have been adopted in adequate measure to tip the supply network form into the new heterarchic form. A tension will have existed in the supply network, as this tipping point was reached, and at some point, the new attractor basin would have become established. This change-over point is a potential area for further research particularly because of the highly integrated or tightly coupled nature of many supply networks.

8.3.5 CAS and the firm

In addition to finding archetypal patterns like those above, complex adaptive systems theory is also concerned with ways in which change occurs, such as the three components (semi-structure, links in time and choreograph transitions) found by Brown and Eisenhardt (1997; 1998). The dynamics of commercial aerospace manufacturing firms in operational supply networks appears to be one in which there is continuous improvement but not radical change, fixed suppliers with little product innovation freedom, but also one which can meet big fluctuations in demand seemingly enabled by risk-sharing and a reluctance to pass on costs to customers. We might describe this as capacity and resilience to do more or less of the same but incapacity to do anything very different. This is quite different from new supply networks, which are inclined to be technologically and organizationally radical.

The notion of ‘near decomposability’ (Simon, 2002) is being applied in the modularization and standardization of components, and appears paradoxically to enable customization. The use of standard components is also supporting less waste and flexibility for use on other manufactured products.

8.3.6 CAS and the supply network

The overall supply network is self-organised in that control is disseminated across many firms in the supply network.

This thesis suggests that the supply network is a form of evolutionary transition (Maynard Smith and Szathmáry, 1995). The structure of the supply network is dynamic in that it accommodates the flow of goods, information and services, and the structure evolves over time through continuous improvement. The tightly coupled connections between firms in the supply network are of particular interest because firms that are formally networked, or connected firms that maintain ties, can outperform rivals (Murmann, 2003). The assumption made is that more highly performing supply networks are more evolved.

We have noted the pattern of change in the commercial aerospace supply network from vertically integrated to a heterarchy and theorise that as 1st tier firms become specialists, essentially acting in a variety of industries to create customized products using standard components, then 1st tier firms become important nodes in many supply networks. Formal relationships will exist with many customers and many suppliers so the presence or contribution of such 1st tier firms to their supply networks are not likely to differentiate competing supply networks. It follows, therefore than it will become the 2nd tier (or the more diversified suppliers) who are perceived as remaining aligned to the primes that will provide supply network differentiation and competitive advantage. It is the 2nd tier who will gain access to commodity parts and raw materials and who will provide competitive advantage to the primes, assuming the continuing systems specialization of 1st tier systems providers.

In other supply network archetypes, for example, the vertically integrated or the Keiretsu, the prime dominates its ‘1st tier’ because they do not supply to other firms.

And in the 4PL™, resources are moved from each firm to the logistics provider and are also dedicated to a single supply network. If there is a fall in demand, it is the prime, or 4PL™ who have to create resilience by selling to new markets or reducing workforce and other assets. Resilience is not spread across the supply network. The heterarchy archetype offers the benefits of demand flexibility which these other archetypes do not. And this resilience is created by means of risk-sharing partnerships in the heterarchy.

For the firm, once embedded in only one supply network, evolution will be constrained by the supply network. For a firm embedded in multiple supply networks, it can continue to evolve outside of the complex adaptive systems in which it is embedded.

8.4 Revised Coevolutionary Conceptual Framework

This section revises the coevolutionary conceptual framework presented in Chapter 4. The assumptions made in Section 5 of Chapter 4 are not challenged by this thesis. For many of the assumptions, examples can be found in substantiation. For example, the Cladogram produced in Chapter 3, identifies the major bifurcations in the evolution of aerospace supply networks. The findings of the thesis revise the four aspects: structure, integration, dynamics and coevolutionary effects of the initial Coevolutionary Conceptual Framework into three aspects structure, integration, and coevolutionary dynamics. It has been not been possible to separate the dynamics from coevolutionary effects and nor has it been desirable upon consideration. The messy micro dynamics contribute to coevolution in the supply network whether intended or otherwise. And this learning when interpreted, sometimes by those within the supply network but also by analysts or professional groups in the industry, triggers intervention such as structural change or more or less of the dynamics in question. It is a chaotic learning process in which local, or firm performance, is the prevailing driver for supply network membership. Once the supply network is better understood as an evolutionary transition of the firm, it will be legitimized as the primary unit of competition and so of natural selection.

8.4.1 Structure

Constructs relating to the structure of the supply network as a complex adaptive system, are found in the case studies and the questionnaire survey. Construct poles are shown to indicate the previous state of the supply network. The structure of the supply network was expected to be rooted in constructs such as ownership versus independence, large versus few numbers of direct suppliers, short versus long relationships. These characteristics are now more clearly defined as shown in Table 8-1. The consequences of adopting the Construct are stated, together with the firms in which they are observed, and where relevant if they are strongly evident in the survey.

Structure		Consequence	Observed in
Construct	**Pole**		
Globalized	Localized	Wide geographical dispersion of suppliers based on skills available; Some use of low-cost economies; Transfer of manufacturing to LCEs for cost efficiency; Some use of low-cost economies for low value add manufacturing	Prime, OEM(A), OEM(B), SecondT
Consolidated	Fragmented	Few suppliers; network is less dense (at 1st tier); Growth in the size of 1st tier firms but a reduction in the number of them; 2nd tier suppliers consolidating in order to meet increased demands of OEM(B)	Prime, OEM(A), OEM(B)
Specialized	Diversified	1st tier supplying multiple customers belonging to multiple industries	Prime
Fixed Suppliers	Suppliers not fixed	Once implemented, the supply network is fixed, bar any supplier failures which are not prevented by the Prime	Prime
Partnered	Owned	Reduced control/power so collaboration needed; shared risk; supplier chooses own suppliers; Formal Partnerships & Outsourcing the easily imitable were highly performing in the survey	Prime, Survey
Systematized	Component-sourced	1st tier delivering integrated systems, simplifying increasing complex components and supply chain relationships; Subcontracting whole systems and sections were important to 1st tier firms in survey	OEM(B), Survey
Fewer Product Systems	Many Product Parts	As product complexity is increased (could be supplier driven R&D innovation using new technologies), parts are bundled into product systems. New supply networks are created with fewer, and consolidated suppliers, who produce complex product systems; the Prime needs to manage fewer suppliers but each is of greater risk; Prime loses technological *build* knowledge to the supplier	Prime
Buyer influence on manufacture sourcing	National influence on manufacture sourcing	Buyer power increasing, so that future airline owning nations can insist on own country as source of manufacture, rather than the use of Prime home nation suppliers	OEM(B)
Good long-term relationship	Poor long-term relationship	Trust and delivery performance are to be expected from a good long-term relationship	OEM(B)
Disintermediated	Supplied	Suppliers and other firms providing services for OEM(A)'s products, disintermediating OEM(A)	OEM(A)
Value-added process manufacturing	Commodity manufacture and assemble	2nd tier becoming more specialist in process technologies and outsourcing simple manufacturing	SecondT

Table 8-1 Revised Conceptual Framework: Structure

The pervasive construct of structure is that it is globalized and so spread across multiple nations, economies and cultures. A consistent driver for globalization is the strategic advantage of cost efficiency however a growing driver in the availability of skills and capacity. A second important construct of structure is that many suppliers have consolidated, providing systems and assemblies which were previously supplied by a fragmented supply network. A third construct is that of systematization, in which suppliers are adopting programmes of their customer's work, in the design and production of systems which can be integrated into the jetliner. This has arisen from higher roduct complexity. The last important construct is that the supply network is partnered: it is an heterarchy, in which the primes are no longer vertically integrated with their suppliers, but in which there are risk-sharing partnerships and suppliers extending their solutions to many customers in more industries.

8.4.2 Integration

The integration aspect of the coevolutionary conceptual framework defines the protocols and methods used for the interaction. Standards are mentioned by all firms in the case studies, and the ability to adopt global standards for interfaces, rather than local or national standards, is helping to reduce costs. The ability to use a global ICT infrastructure and shared systems is particularly important for the Prime and the OEMs appear to lag the electronic collaboration evident at the top level. Integration of designs is being achieved by the collaboration of many firms in the supply network. Integration of a global nature recognizes the challenges of different cultures, more so than language or distance. Table 8-2 lists the integration constructs and poles, together with stated consequences and the relevant case studies.

Integration		Consequence	Observed in
Construct	Pole		
Global ICT infrastructure and systems	Traditional mainframe computing	Networks and computing power is distributed to anywhere in the world; systems can be accessed from any location	Prime
Global interface standards	National standards/ Local Standards	Interface protocols understood providing a shared language for producing integrated parts; Common standards used permitting the same components to be used in product solutions for various customers.	Prime, OEM(A)
Ability to Handle Cultural Differences	Inability to Handle Cultural Differences	Cultural differences are understood, managed and acted upon with empathy	Prime
Integrated designs	Bi-lateral designs	Customer, OEM(A) and supplier, three way integrated designs and solutions	OEM(A)
High Customer Empathy	High Customer Empathy	Suppliers who understand OEM(B)'s customer specifications and have a good relationship with the Prime, are preferred	OEM(B)
Western quality standards	Eastern quality concerns	Western quality systems are not easily adopted in LCEs	OEM(B)
Multiple customers requiring unique products using process technology innovation	Multiple customers with identical manufactured assemblies	More box-builds and electronic assemblies being created, but each is more customized creating niche specialisms at 2nd tier. Standard components mean less waste and use on other manufactured products.	SecondT

Table 8-2 Revised Conceptual Framework: Integration

8.4.3 Co-evolutionary dynamics

This new category brings together the categories of dynamics and coevolution in the initial conceptual framework. The dynamics as originally perceived, such as frequency, magnitude, importance etc were not identified as very important to the supply network. In fact, some parts which were supplied very infrequently in small magnitude were very important, or which were sourced from unique suppliers or from scarce raw materials, regardless of their frequency and magnitude, were also very important. In contrast to this, the case studies and survey highlight the coevolutionary dynamics in which behaviours from the firm influence the supply network performance, resulting in feedback and mutual adaptation.

The coevolutionary dynamic appears to have two faces: one that reflects the operational supply network once it is established, and the other, that mirrors a forming supply network. The construct column in Table 8-3 is more typical of an operational supply network, whereas the pole describes the new or emerging supply network. Aspects to note is that overall, the operational supply network is much better performing, as processes for continuous improvement, cost efficiency, responsiveness to demand and multiple markets, sharing information are well-embedded. The emerging supply network is far more radical in its innovation offering and overall, efficiencies and performance are not well established. Suppliers have not worked out how to improve process technologies or how to add value to components. There is opportunity to build these in at the start.

Coevolutionary Dynamic		**Consequence**	**Observed in**
Construct	**Pole**		
Large demand fluctuation	Predicted demand	Having diversified suppliers increases the risk of precision delivery; supplier risk of failure is during the up-turn	Prime
Multiple market responsiveness	Single industry focus	Supplier learns to meet the needs of other industries and brings that learning to the aerospace industry by way of innovations, improvements, which can be adopted by the Prime.	Prime
Value-added products; Process Technology Innovation	Commodity Products; Commodity assembly and manufacture	Suppliers can learn and develop more value-add to products, increasing their likelihood of becoming selected for new supply networks. New methods for process improvement from industry and wider technological breakthroughs, providing opportunities for specialization	Prime, SecondT
Services sold	Products sold	Flight hours are sold, requiring new business models throughout the supply chain and moving away from maintenance and repair cash cow.	OEM(B)
Information translucency	Information Transparency	Prime to supplier sharing, translucency of information, risk of competitors gaining access	Prime
Information/ Knowledge Sharing	Withholding Information/ Knowledge	Mutual sharing of information, better warning of fluctuations in demand and supply network performance	OEM(A), OEM(B)
Easy dialogue with suppliers	Difficult dialogue with suppliers	The dynamic with the supplier permits easy dialogue	SecondT

Coevolutionary Dynamic		Consequence	Observed in
Construct	**Pole**		
Investment in Supplier Training	No investment in supplier training	The prime invests resources in training of suppliers	Prime
Continuous Improvement/ rising 2nd tier capabilities	Stagnation/ falling capabilities/ no improvement	Improvements in production may be identified by either the Prime or the supplier, leading to continuous improvement; Preferred supplier standards continuously improving; Proactive supplier development	Prime, OEM(A), OEM(B)
Continuous Improvement but design stagnation	Radical Innovation	Once implemented, the jetliner (and the manufacturing process) is continuously improved, never radically innovated; Radical innovation are closely monitored; The survey top result for the Prime was a culture of continuous improvement	Prime
Consistent quality	Inconsistent quality	Reputation of OEM(A) is maintained by sourcing goods from fewer preferred suppliers providing consistently high quality goods. Supply network consolidation as other suppliers may be acquired or go under	OEM(A)
Consistent performance – time, cost, quality and agility	Inconsistent performance	More demanding of suppliers as more component suppliers available globally who can meet demand fluctuations to the required time, cost and quality criteria. SecondT able to meet demand and extend	SecondT
Lean and Kanban techniques	High inventory and excessive waste	Improved delivery and inventory management, becoming responsive to demand fluctuations; Waste is removed as a consequence of lean practices in the supply network	SecondT
Distant monitoring by Customer (Prime)	Close monitoring by Customer (Prime)	Behaviours required by the Prime rippling through OEM(B) to suppliers	OEM(B)
Technology automation	Low-cost Labour	Replacing labour with technology an alternative to outsourcing to LCEs	OEM(B)
Cost Efficient	Not Cost Efficient	Suppliers who are cost efficient are preferred	OEM(B)
Competitive Suppliers	Suppliers holding power	Competitive supplier bring lower costs and innovation to the supply chain	OEM(B)
Commodity supplier able to meet demand	Preferred suppliers lacking inventory – stock-outs	Preferred commodity suppliers losing business as not able to deliver in time, extending the supply network to others	SecondT

Table 8-3 Revised Conceptual Framework: Coevolutionary Dynamics

8.4.4 The survey

This final subsection takes a look at the results of the survey with regard to the revised coevolutionary conceptual framework. The survey found three clusters of high performance. These were:

1. partnerships, quality management, lean methods and sharing knowledge
2. high level collaboration, long-term relations, supplier development, investment in training
3. supplier monitoring, flexible operations, market responsiveness, high-level planning and control and outsourcing the easily imitable.

Each cluster is primarily formed of coevolutionary dynamical constructs but each also has one structural construct. This suggests a close synergy between that structural construct and the related coevolutionary dynamics. None of the clusters contain an integrational construct. This may be a limitation of the survey instrument and is discussed in the next section.

8.4.5 Summary

This section revised the coevolutionary conceptual framework presented in Chapter 4. It classified the specific constructs found in the empirical studies into three aspects of coevolution: structure, integration, and coevolutionary dynamics. The conceptual coevolutionary framework is now contextualized in commercial aerospace manufacturing.

8.5 Contribution and Limitations

All research questions set out in Chapter 1 have now been answered and all outcomes are delivered. However, the contributions are many and varied, within the perspective of complex adaptive systems. This section sets out the contributions, how to find them in the thesis and describes the known limitations. Any errors remaining in the document despite several iterations of its text are mine and for these I am sorry.

8.5.1 Overall research contributions

The contributions made by this thesis are noted in this sub-section. Whilst there are various contributions, there are two key types of contribution to the complexity and management literatures.

The first provides a methodological contribution addressing a significant research gap in the lack of appropriate methods to conduct complexity research. For this reason Question 2 is included explicitly, rather than leaving the question of methodology as simply a part of the thesis preparation process. There are four aspects to the methodological contribution. First is that it takes an holistic approach; he need for qualitative, process and holistic types of research (i.e. using a complex systems lens) is increasingly appreciated (Maguire et al., 2006) although this research is not limited to qualitative data. Second is the particular research strategy and research design which can be replicated in other studies of complex adaptive systems. A mixed methods research strategy (Brannen, 2005) also known as multi-strategy research (Bryman, 2004) was used, drawing in relevant information in a variety of ways from practice and improving the validity of the research findings. The particular ordering and logics of the mixed methods strategy is unique to this study, and the possibility of re-applying the mixed methods strategy is a contribution to research methodology using the complex systems lens. The third is in overcoming the main challenge of applying complexity science methods in ascertaining appropriate variables and in definitional and measurement respects (Maguire et al., 2006; Pathak et al., 2007).

The methodology incorporated a process to operationalize complex systems' constructs to variables, connecting theory with practice. Fourth is the structure of the survey instrument and the analysis method used for the survey. It follows from this work is that it is a method of enquiry into inter-firm dynamics that allows us to examine how different characteristics, be they practices, techniques, tools or targets actually affect performance. This takes into account not only the direct effects of the practice, technique, tool or target, but also the interaction between them. This is of great importance for strategy, planning and policy in both the private and the public sectors.

The second key contribution is a conceptual contribution to complexity and management literatures. The coevolutionary conceptual framework which provides an answer to question Q3c: "*How do supply chain dynamics relate to supply network structure*?" In particular it has potential for developing a new theory to explain the coevolution between layers of complex adaptive systems. Examination of this particular evolutionary transition (from firm to supply network) has not been examined in this way before. The creation of a coevolutionary conceptual framework for commercial aerospace manufacturing and its potential for generalization to studies of other complex adaptive systems is a key contribution. The framework draws together characteristics of structure, integration and coevolutionary dynamics. Very few researchers have attempted to describe the dynamics of firms (Tsoukas and Chia, 2002) and so in this respect a coevolutionary dynamical perspective is novel. The identification of structural, integration and coevolutionary dynamical constructs is described and based on data analysis of interview and survey results.

Other contributions from this research are noted below.

This is an empirical study of the commercial aerospace manufacturing sector relating to jetliners with 100 or more seats. Other studies have not used primary data across this entire sector using a complex systems perspective.

Next are the challenges and extensions made to existing evolutionary and coevolutionary theory in the context of commercial aerospace manufacturing supply network. It is only since 2001 (Choi et al., 2001) that supply networks have been recognized as complex adaptive systems. These extensions to theory should be progressed to peer-review and publication.

The last is the specific findings of high performing constructs and clusters for commercial aerospace manufacturing which should resonate with practitioners. These are summarised in Table 8-4 indicating the location in the thesis for further information.

Summary of contribution	**Chapter, Section and Reference if any**
METHODOLOGICAL CONTRIBUTION	
Use of a complex adaptive systems perspective as an holistic approach to the empirical study of supply network evolution	Ch4, Sect3 & Ch8, Sect3 (Complex Adaptive Systems Perspective) Ch4, Sect4 (Research Philosophy)
The application of a complex adaptive systems perspective to an empirical study using a mixed methods research strategy	Ch5, Sect2 (Research Design)
The definition of a process to operationalize complex systems' constructs to variables, connecting theory with practice.	Ch4, Sect3, Ch 5 Sect 2
The identification of constructs and variables in the coevolutionary dynamics of the firm and the supply network	Ch6 (Aerospace Case Studies) Ch7 (Aerospace Questionnaire Survey)
The survey design and method as tool for performance analysis	Ch6, Sect4 (Questionnaire survey methodology)
CONCEPTUAL CONTRIBUTION	
The creation of a coevolutionary conceptual framework for understanding the coevolutionary dynamics between two layers of complex adaptive systems	Ch4, Sect5 (original Coevolutionary Conceptual Framework) Ch8, Sect4 (revised Coevolutionary Conceptual Framework)
The identification of structural, integration and coevolutionary dynamical constructs, based on data analysis of interview and survey results	Ch6 (Aerospace Case Studies) Ch 7 (Aerospace Questionnaire Survey)
OTHER CONTRIBUTIONS	
Use of a complex adaptive systems perspective in the empirical study of commercial aerospace manufacturing	Ch4, Sect3 & Ch8, Sect3 (Complex Adaptive Systems Perspective) Ch4, Sect4 (Research Philosophy)
The challenges and extensions for existing evolutionary and coevolutionary theory in the context of commercial aerospace manufacturing	Ch4, Sect1 & Ch8, Sect1 (Evolutionary Theory) Ch4, Sect2 & Ch8, Sect2 (Coevolutionary Theory
The identification of high performing constructs and clusters in commercial aerospace manufacturing; and for the purposes of achieving particular performances (incl. cost, quality); and at particular tiers in the supply network	Ch 7 (Aerospace Questionnaire Survey) Ch 8 Sect 4 (Revised Conceptual Framework)

Table 8-4 Research Contributions – within thesis references

8.5.2 Research contributions to practice and policy

For practice, high-performing clusters of constructs and variables within commercial aerospace manufacturing are identified. This could indicate the characteristics that a high-performing firm and supply network might aspire to adopt. The results also show the less well performing variables (inter-firm characteristics) and these might indicate to practice those that ought to be revised or withdrawn.

Also, for practice, the survey method which captures both first-order expected performance outcomes and interaction/pair-wise effects of characteristics is an approach that could be used to examine other units of coevolutionary dynamics, for example, the team within the firm, the supply network in the industry. The approach is possibly even more generic in that it could be used to analyse an individual's performance.

For example, if it was used to examine life-style, then characteristics such as, diet, exercise, liquid intake, alcohol consumption, social interaction, education involvement, employment/work demands/rewards, and so on. Specific characteristics could be developed for each, examining how each contributed to the overall health of the individual. The trade off between performance outcomes, such as happiness, health, longevity and so on would be exposed. The most highly performing clusters could be found which would indicate the appropriate balances between diet, exercise, work etc.

Finally, for policy, there are three implications.

The first is the application of the three corner-stones of the coevolutionary conceptual framework (structure, integration and coevolutionary dynamics). For the stimulation of a complex adaptive socio-economic system, it is suggested that all three parts are required. Whereas for a biological system, structure is stochastic and self-organizing, in a socio-economic system, it is possible to intervene, such as outsourcing, systematizing, consolidating as we have found in the thesis. Also, methods of integration, that is the routes enabling coevolutionary dynamics, may be targeted to stimulate more coevolutionary dynamics, or new ones.

The second implication for policy is that the supply network may need legitimizing in some form. This is already the case with the Keiretsu archetype in Japan, and should be examined as a way to aid strategic competitive advantage of supply networks.

Third is that development in low cost economies is critical to meet the demands of the supply network. Innovation is a central role in the process, as is the capacity for an economy to develop, integrate and adapt to novelty (Metcalfe and Ramlogan, 2008). This may be supported by policy decisions.

8.5.3 Limitations of the research paradigm, the methodology and the data

The limitations of the thesis are contained in this sub-section. Three types of limitation are included: those related to the research paradigm, the methodology and the data. They are presented separately in this sub-section.

8.5.3.1 Limitations of the research paradigm

The complex systems perspective has permitted a dynamical view to be taken of the coevolution of the firm and the supply network. But in identifying the dynamics, specific properties of the dynamic have not always been captured, such as magnitude, longevity, embeddedness. For some, such as consistent quality, the property is captured, but for lean practice it is not. Arguably, the ratings by respondents go some way to ameliorating this limitation, for example, a score of 1 for lean practice would suggest that there is very little, whereas a score of 9 suggests peak lean practice.

The research paradigm is firmly based in a coevolutionary epistemology. A different research paradigm, for example, one based in ideologism or Critical Theory (Guba, 1990) such as feminism, taking a subjectivist epistemology, and dialogic methodology, would aim to highlight false beliefs and to identify transformative methods to correct false beliefs. The research paradigm of this research has been to examine mutual adaptation between two levels of complex adaptive system. There has been no intention to judge what is right or wrong.

The description of the internal diversity of a firm and supply network may be described by other researchers using different characteristics along different dimensions; it is not absolute in the way that biological DNA has 23 pairs of chromosomes. Whilst I have found particular characteristics of interest, other studies may legitimately find others. In a similar way, the phenotype (or form) of a firm or supply network, may be perceived differently by others. A different Cladogram may find different results although we would expect close consensus, and absolute fact, should it ever arise, may only be the case after the demise of the industry and once the terminology we use to describe characteristics and forms is no longer evolving.

8.5.3.2 Methodology limitations

Except at Stage 1 of the Research Design, no attempt was made to embrace the wider scope of each firm. A focus upon commercial aerospace manufacturing by default excludes investigations of other operations within the same firm. Most firms generated products and services for the defence industry and also for the space sector, such as satellites and related technologies. Some firms had a great diversity of industries to which they supplied more commodity level products, such as engineering components. Some firms belonged to larger groups involved in other partially related industries, such as security. By excluding these other aspects of each firm, which were to more or less a degree integrated within the firm, this study takes only a partial perspective. The study could have identified and dealt with details relevant for the purposes of manufacture for these other industries. Future investigations may be able to control for this by specifically identifying these aspects of inter-firm characteristics. It may prove difficult if not impossible to unravel this integration as this bundling is exactly what contributes to firm uniqueness and competitive advantage.

There is limited generalisability from the sample of commercial aerospace manufacturers to all commercial aerospace manufacturers, since only four firms are examined in detail, albeit at three different tiers of the supply network. The generalisability of the survey results to all commercial aerospace manufacturers is possible, but limited to the extent that most firms in aerospace manufacturing also manufacture for defence and space industries.

The use of repertory grid technique has raised the importance of defining construct poles. In the survey inter-firm characteristics are measured along one dimension, for example long-term relations, is measured along time. The repertory grid interviews showed how long-term relationships could be good or bad. To exacerbate this not all long-term relations will be the same. Inter-firm characteristics are not homogenous across all suppliers, so when a respondent completes the questionnaire survey, it is not clear whether they are considering a typical supplier, an overall impression of all suppliers, the most recent supplier or something else. The existence of long-terms relations per se is not an adequate indicator of performance. In an attempt to mitigate this weakness, other slightly overlapping characteristics are included. For example, 'Arms Length Relations' is generally scored very low, whereas long-term relations scores high, giving some confidence that longevity of relationship is a reasonable indicator of performance.

The most significant limitations for repertory grid technique are interviewee reluctance to identify reasons why constructs are important; interviewee inability to differentiate the elements of the grid, even if self-selected; and artefact related issues, such as surface-level triviality during interview (Daniels et al., 2002). A further limitation is the number of distinctions or constructs that a typical respondent can identify, which is around 10 to 12 (Reynolds and Gutman, 1988). Some distinctions which are important may not elicited during limited interview time. Multiple repertory grid interviews mitigate this somewhat.

The survey approach produces a snap-shot in time. It does not say anything about how the characteristics came to be similar, nor how they might diverge, consolidate, diminish or be replaced by other characteristics in the future. It is thus a static perspective within a larger research design. The overall research design attempts to contribute to a description of the dynamics of the aerospace supply network over a period of time.

The survey looks only one way in the supply network, at suppliers. It could look at other connections such as customers, competitors, allies, collaborators, sources of industrial and professional development, that is, at all other firms with whom the firm has a relationship. The characteristics are likely to be somewhat different for each type of relationship, but an analysis of this sort might provide an even more rounded coevolutionary description of the firm.

Regarding the process of clustering of data, a limitation is that most methods of clustering are deterministic and will produce a cluster solution regardless of natural structure existing in the data (Ketchen Jr. and Shook, 1996; Arabie and Hubert, 1994). And of course, different methods or different clustering choices will produce different results and involve subjective decisions. Best endeavours have been made to use the most resilient selections which have been tested via split-half methods and comparison of variable means between clusters and the whole data set. Evaluation by other means, e.g. Monte Carlo simulation, has not been attempted.

The null hypothesis is that the data are sampled from a uniform distribution (Hartigan, 1975) which leads to conservative error rates if the population has a unimodal distribution , e.g. has a normal distribution. This is not to say that the population is unimodal and further research could extend the validity of the findings in a multimodal distribution. Ormerod (1994) raises the notion of multiple equilibria in the economy thus making it impossible to identify an optimal competitive equilibrium.

Finally, with respect to the survey, data was captured in two alternative ways (first order and pair-wise) which were analysed in three ways: just first order data, combination (equally weighted) of both sets of data, and just pair-wise data. The final results for each set of cases considered all three analyses and reported on consistent results between the three scenarios. Whilst this technique mitigated reliance on results which were accurate using only one or two of the data analyses, it may at the same time have inadvertently triggered the removal of accurate results. Further, the choice of equal weighting was arbitrary to give equal importance to each type of data. The weighting could have been 9:1 or 1:9 or some other ratio rather than 1:1. For this reason the reliability and consistency of the results obtained from the survey should be considered a methodological limitation.

8.5.3.3 Data limitations

Access to targeted firms, whether outliers or mainstream, may have produced different outcomes in the results presented here. The commercial aerospace industry is dominated by a duopoly consisting of Boeing and Airbus (EADS). One of these firms took part in the case study and both took part in the survey. Whilst every attempt was made to solicit at least survey input from all firms in commercial aerospace, the actual firms who contributed to the case studies were willing and known participants. Their interpretations may not be typical of the industrial sector.

The relevance and application of all 27 characteristics to commercial aerospace manufacturing was assumed for all firms. This assumption was tested in two firms by requesting the respondents to mark the characteristics which were used by the firm. For one firm, most of the characteristics were relevant and in another, only one third were relevant. Some respondents scored zero for some characteristics, perhaps indicating that the characteristic did not apply to them. It is possible that some respondents scored characteristics based on their past experiences or knowledge (formal or otherwise) rather than their applicability to the firm. A learning point for future use of the survey data collection method would be to include only those used by practitioners. This would also make data collection easier as the volume of data collected from each individual proved tiring for some respondents.

Completion of the diagonal in the pair-wise questionnaire was excluded, as this would ask the respondent to rate the effect of a characteristic on itself, for example, the effect of TQM on TQM. Given that positive and negative feedback operate at all levels, responses could have been solicited for the diagonal.

Each characteristic presented for clustering has equal weighting. It would have been possible to rank the characteristics and perhaps weight characteristics differently to reflect their importance. Otherwise, the actual ratings may provide adequate differentiation and reflect importance.

It is assumed that all respondents understood the characteristics provided in the questionnaire as there was only one query concerning the meaning of a characteristic (11 - offsets as part of sales), which was provided on request. No explanatory text was provided for any characteristic. This could be improved in future questionnaires by including comments within the spreadsheets or alternatively using an electronic instrument which can provide help on request, for example, by the use of button located next to the characteristic name.

The scope of responsibility and knowledge of any one respondent limits the values of the questionnaire responses. In most cases, Directors of Supply Chain completed the questionnaire survey using their knowledge of the entire breadth of the firm's supply chain operations. In some cases, Directors of specific areas, such as mechanical systems, or information technology products and systems, were able to respond more specifically within their scope of responsibility but may have overlooked characteristics adopted by other members of the same firm. There is a trade-off between breadth and depth of knowledge. Breadth of knowledge diminishes the emphasis of specialisms and diversity within different functional units of the firm. Depth of knowledge omits firm-wide practices.

Regardless of the scope of knowledge of the respondent, there are three ways in which a respondent might know how the different characteristics adopted by members of the supply network interact with each other. Firstly, the respondents may have experienced this interaction. The experience may have been a single event and so the knowledge may be superficial or very specific to the event. Alternatively, the experiences may have been many and regular and relied upon by the respondent indicating a greater belief in the integrity of the rating. All experiences will have occurred under a unique set of environmental conditions in any event. Secondly respondents may have learnt the knowledge of the interaction, by training or by the sharing of understood knowledge with associates, without actually experiencing it. Lastly, they may have guessed at the relationship in order to provide a complete questionnaire response. We cannot say which type of knowledge the respondent relied upon. Our form of mitigation with respect to 'guesswork' is the seniority of the respondents which itself introduces some limitation regarding the timely relevance of their most recent operational experience. The responses therefore cannot be relied upon as facts but only as beliefs.

Although there was an opportunity to add characteristics and performance outcomes which may have been omitted from the questionnaire, no-one did so. This could have been as a consequence of the length of the questionnaire. There may have been a missed opportunity to include emerging characteristics and performance success criteria. One such criterion is evident in public domain information and is ecological sustainability.

8.6 Further Research

This research has addressed in some small way, some of the research gaps found in the traditional literature on firm and supply network coevolution presented in Chapter 3. These are considered before suggestions for future research are presented.

A paradigm shift to complex adaptive systems view and a coevolutionary dynamical view holds promise for future research addressing Daft and Lewin's (1993) observation that firms were changing cataclysmically with respect to networks. This paradigm shift is beginning and this thesis supports the move. The seeds of a new theory of supply networks, based in their structural coevolutionary dynamics, are sown here addressing Salancik (1995). This thesis shows that it is possible to know broad features of system evolution, by examining heterogeneous interacting agents as predicted by Levin (2002). This is then a new way of looking at organizational evolution, of the firm and the supply network, to examine the origins of novelty and how new organizational forms emerge (Romanelli, 1991). This way also gives primacy to 'organizational becoming' (Tsoukas and Chia, 2002) and a new way to approach change.

The remaining paragraphs in this section list the opportunities for further research. Opportunities to address the limitations of this research can be added to this if so desired.

The research has identified the importance of product service and ‘flight by the hour’ as a likely future business model. The transformations required to the current supply network forms and characteristics would be valuable research for practice and policy.

This research has examined an heterarchical archetype in the commercial aerospace manufacturing. It would be interesting to examine the defence aerospace manufacturing sector or an alternative supply network archetype in order to find comparisons and contrasts.

The emerging performance success criterion of ecological sustainability and associated changes in characteristics appears to be one of the future pathways for the evolution of the commercial aerospace industry. It would be useful to examine how existing characteristics would have to generate at least as good as current performance. Also, it would be worth examining potentially new inter-firm characteristics that could aid performance. It is important to note that the environment of the jetliner presented in Chapter 2 is just another complex adaptive system, running at a slower rate than organizational change, however, coevolving with the firm and the supply network.

It would be useful to create agent-based evolutionary models (software programs) which could simulate the success of different structures extrapolating them into likely future environmental scenarios.

A closer look at the life-cycle of jetliner production may be useful, although it appears from the research that once operational it can adapt to demand fluctuation and in any event continues to improve until such time as demand is withdrawn. A more interesting potential research pathway would be to examine the overlaps between supply networks and their mutual synergies and conflicts, so that high performing characteristics might be exposed.

The research design and in particular the mixed methods research strategy could be attempted in other fields to examine coevolutionary dynamics, integration and structure.

The survey analysis, using the two tables (first order performance criteria and pair-wise interactions) could be used in other fields to examine the validity of the methods for identifying high-performing clusters of characteristics in other fields of study.

8.7 Closing Remarks

This section reflects on the thesis and presents my final thoughts.

My own expectations in using a complex systems perspective were to find indications of evolution in: 1) modularity and decomposability of components will increase the overall fitness of the firm and its capability to mutate (Simon, 2002); 2) integration and aggregation (Holland, 1995) of components in a synergetic manner (Allen, 1994) that is emergent; 3) non-linearity and feedback causing self reinforcing patterns or structures (Arthur et al., 1987); 4) self-organization (Kauffman, 1995a) and self-reference in the creation of structure through the process of social construction (Hofstadter, 1976); 5) components of systemic survival (diversity, inter-dependence, flexibility, cooperation and partnership, cyclical flow of resources (Capra, 1996); 6) irreversibility (Prigogine, 1955) and path-dependency the past co-producing the present and the future (Maguire et al., 2006). I did not expect these to be challenged and nor were they. There were however some surprises in the research.

1. The growth in size and power of 1st tier firms is shaping the supply network in unexpected ways.
2. The learning and training available in the supply network is creating mutual adaptation of the firm and the supply network.
3. Dynamics cannot be separated from their effects and the feedback they instigate.

4. Combinations of different characteristics or the same characteristics in different measures, can produce the same performance outcome. This means that more than one path is possible to achieve the same ends.
5. Clusters of high performance bring together characteristics which are both structural and dynamical.

Whilst shedding some light on structure, integration and coevolutionary dynamics between the firms and the supply networks in the commercial aerospace manufacturing sector, I am of the view that we live in an ecology of ignorance (Luhmann, 1998) creating complexity in trying to deal with complexity and creating new ignorance in trying to know (Medd, 2001). Complexity is above all a statement of our limits of knowledge (Allen, 2001b).

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APPENDIX A – Research Record

A.1 Publications

Varga, L., Allen, P.M. (2009) ‘An Ecological Perspective on Supply Networks’, **invited paper** for Special Edition of Emergence, Complexity and Organization, on Supply Networks as Complex Adaptive Systems, submitted Nov 2008

Rose-Anderssen, C., Baldwin, J.S., Ridgway, K., Allen, P.M., Varga, L. and Strathern, M. (2008) ‘The evolution of commercial aerospace supply chains and the facilitation of innovation’, *International Journal of Electronic Customer Relationship Management*, Vol. 2, No1, pp. 63-84.

Rose-Anderssen, C., Baldwin, J.S., Ridgway, K., Allen, P.M., Varga, L. and Strathern, M., (2009) ‘A cladistic classification of commercial aerospace supply chain evolution’, *Journal of Manufacturing Technology Management*, Vol. 20, No. 2, In Press.

Rose-Anderssen, C., Baldwin, J.S., Ridgway, K., Allen, P.M., Varga, L. and Strathern, M. (2008) ‘Aerospace supply chains as evolutionary networks of activities: Innovation via risk-sharing partnerships’, *Creativity and Innovation Management*, Vol. 17, No. 4, pp. 304-318

Rose-Anderssen, C., Baldwin, J.S., Ridgway, K., Allen, P.M., Varga, L. and Strathern, M. (2009) ‘Knowledge transformation, learning and changes giving competitive advantage in aerospace supply chains’, *Emergence, Complexity and Organization*, Vol. 11, No. 2, In Press.

Allen, P.M. and Varga, L. (2007), 'Complexity: the Co-Evolution of Epistemology, Axiology and Ontology', *Non-Linear Dynamics, Psychology and Life Sciences*, Vol. 11, No. 1, pp 19-50

Allen, P. and Varga, L. (2006), “A Co-Evolutionary Complex Systems perspective on Information Systems”, *Journal of Information Technology*, 21(4)

Varga, L. and Allen, P.M. (2006), “A case-study of the three largest aerospace manufacturing organizations: An exploration of organizational strategy, innovation and evolution”, *Emergence-Complexity and Organization*, 8(2): 48-64

Baldwin, J.S, Rose-Anderssen, C., Ridgway, K., Allen, P.M., Lopez, A. Strathern, M., and Varga, L., (2006) ‘Management Decision-making: Risk Reduction through Simulation’, *Risk Management: An International Journal* (Palgrave), 8 (4), 310-328

A.2 Book Chapters

Allen P M, Strathern M and Varga L, “Complexity: the Evolution of Identity and Diversity” in *Complexity and Diversity. The problem of difference and identity*, Cilliers FP and Juarrero A (Eds). Stellenbosch: Stellenbosch Institute for Advanced Study (STIAS). To appear.

A.3 Papers in review

Allen, P.M., Varga, L., Strathern M., Rose Anderssen C., Baldwin J., and Ridgway K. ‘*Complexity, Evolution and Organizational Science’*, submitted for publication to Organization Studies.

Rose-Anderssen, C., Baldwin, J.S., Ridgway, K., Allen, P.M., and Varga, L. *‘Strategies for aerospace supply chain practices – A cladistic approach’*, being reviewed at International Journal of Operations and Production Management.

Rose-Anderssen, C., Baldwin, J.S., Ridgway, K., Allen, P.M., and Varga, L., *‘Emerging practices of integration and coordination through communicative interaction in an aerospace supply chain for innovation’,* Sent to Journal of Management Development.

A.4 Book chapters in progress

Varga, L; Baldwin, J; Rose-Anderssen, C; Allen, P M; Ridgway, K (2008), 'Evolutionary Manufacturing Networks: Models of Complexity' in ***"**Enterprise Networks and Logistics for Agile Manufacturing"* by Lihui Wang and S. C. Lenny Koh (eds.).

A.5 Conferences and Conference Papers

Varga, L, P.M. Allen, M. Strathern, C. Rose-Anderssen, J. Baldwin and K. Ridgway (2008) '*An Ecological Perspective on Supply Networks'* presented by Liz Varga at the 4th Organization Studies Workshop, Cyprus, 5th-7th June

Varga, L (2008) '*A Coevolutionary Perspective on Supply Networks'* presented by Liz Varga at the Cranfield Multi-Strand Conference "Creating Wealth Through Research and Innovation", 6th & 7th May

Varga, L, P.M. Allen (2008) '*Aerospace Supply Network Performance'*, poster session hosted by Liz Varga at the Cranfield Future of Manufacturing Research Day, 5th May

Varga, L (2008), '*A Typology for Corporate Responsibility Evolution: The Questions we Might Ask*' submitted and rejected by Academy of Management (AoM) annual meeting, 8-13 August 2008, Anaheim, CA, USA

Varga, L (2008). '*A Typology for Corporate Responsibility: Profitable and Sustainable'* presented by Liz Varga at the "Corporate Responsibility & Sustainability: Leadership and Organisational Change" - The 7th Annual Colloquium of the European Academy of Business in Society, 10 – 12 September 2008

Varga, L. (Feb 2007), '*Repertory Grid in Organization Studies'*, People And Science: Sharing Methodological Insights, cross-University conference, Stafford Cripps Building, Cranfield University

Varga, L. (Jan 2007), '*A typology for Corporate Responsibility (CR) maturity'*, EABIS CSR Platform (EU framework 6 project), Cranfield University

Allen, P.M. and Varga, L. (Jun 2006), '*Complexity and the evolution of supply chain structures'*, EIASM Conference, Oxford

Allen, P. and Varga, L. (Sep 2006), "*Social and Economic Complexity: the co-evolution of Reality, Knowledge and Values*", European Conference on Complex Systems (ECCS), Oxford University

Varga, L. (2005), "*Inter-connectivity in Organizations: Conflictual Diversity as a measure of Evolution*", Complexity, Science and Society Conference, Liverpool University

Varga, L. and Allen, P.M. (2004), "*A case-study of the three largest aerospace manufacturing organizations: An exploration of organizational strategy, innovation and evolution*", CRIC, Manchester University Nexsus conference

APPENDIX B – Research Methods

Research Method	**Used in Papers/Conferences**
Classification using N-Vivo (See Appendix B.1)	A Case-Study of the Three Largest Aerospace Manufacturing Organizations: An Exploration of Organizational Strategy, Innovation and Evolution (2006)
Cladistics (See Appendix B.2)	Complexity: the Co-Evolution of Epistemology, Axiology and Ontology (2007) Social and Economic Complexity: the co-evolution of Reality, Knowledge and Values (2006) A Co-Evolutionary Complex Systems Perspective on Information Systems (2006)
Repertory Grid Technique (appendix B.3)	Thesis Repertory Grid in Organization Studies (2007) A typology for Corporate Responsibility (CR) maturity (2007) Inter-connectivity in Organizations: Conflictual Diversity as a measure of Evolution (2005)

B.1 Classification using N-Vivo

Method	Purpose	Issues	Validity	Limitations
Classification using N-Vivo The content of published and publicly-available firm annual reports is coded sentence by sentence to identify constructs used in each report relating to the topic under investigation. The constructs are organized into themes on a within-case basis by clustering constructs that are similar. Content Analysis and Classification using N-Vivo can be used on interview transcripts and other reports/documents with complete prose.	**Used to identify themes from Chief Executive and Chairman reports within published Company Annual Reports** Software used for this was N-Vivo Reports were coded sentence by sentence using content analysis to identify constructs that each CEO (or his writer) had used to describe the firm. The specific words and language used in each CEO/chairman statement plus frequency, positioning (e.g. this 'came first' or 'was most significant') and content size devoted to the content analyzed in order to arrive at some conclusions as to the relative importance of particular constructs.	**Issues with content analysis method using N-Vivo include:** The analysis of annual reports is limited by the points included by CEOs and by their descriptions of these points. Others working in the firm would be able to substantiate the completeness and accuracy of the information resulting in a more accurate analysis. Although the source text is indisputable, the authors' interpretation of the text may differ from either the intended interpretation or a consensus of constructions of the text. Each CEO statement was analyzed in this way and triangulated with business reports (via electronic business data sources) regarding these companies. Where anomalies were found between CEO statements and business reports, some scepticism was recorded against the relative importance of the CEO emphasis. In addition, the companies' web-sites were used to obtain further details of each of the innovations mentioned in the annual reports. Cross-case assessment was carried out as the final stage of analysis to explore the differences and similarities between the cases.	The validity of the classification depends largely on the content of the published report. As the reports are second order data, the classification is an interpretation of this data and may be biased. Data from multiple sources permit some triangulation. The source text is capable of being tested and verified by access to the public documents and so the content used for classification is not disputed. The process used for classification, if clearly defined, should be consistent and repeatable (Miles & Huberman, 1994). The use of other coders, particularly original authors, would increase validity. The use of clear descriptions for each construct aid with explaining the rationale for assigning particular content to a construct.	Limitations of content analysis for Organization Studies: The classifications from a number of firms may be compared to identify similarities and differences across cases. Constructs appearing more regularly are likely to apply generally for firms of a similar size within the same industry. There is limited generalizability from the sample of aerospace manufacturers to all aerospace manufacturers since it is the largest 3 firms that are examined and so are not representative of the population as whole. There are strictly limited inferences that can be made about motivation or intent as a consequence of the content analysis. Resources to carry out content analysis are demanding. Rich ideographic data is explored and insights into individual cases can be established, but this knowledge is not easily transferable to other cases.

B.2 Classification using Cladistics

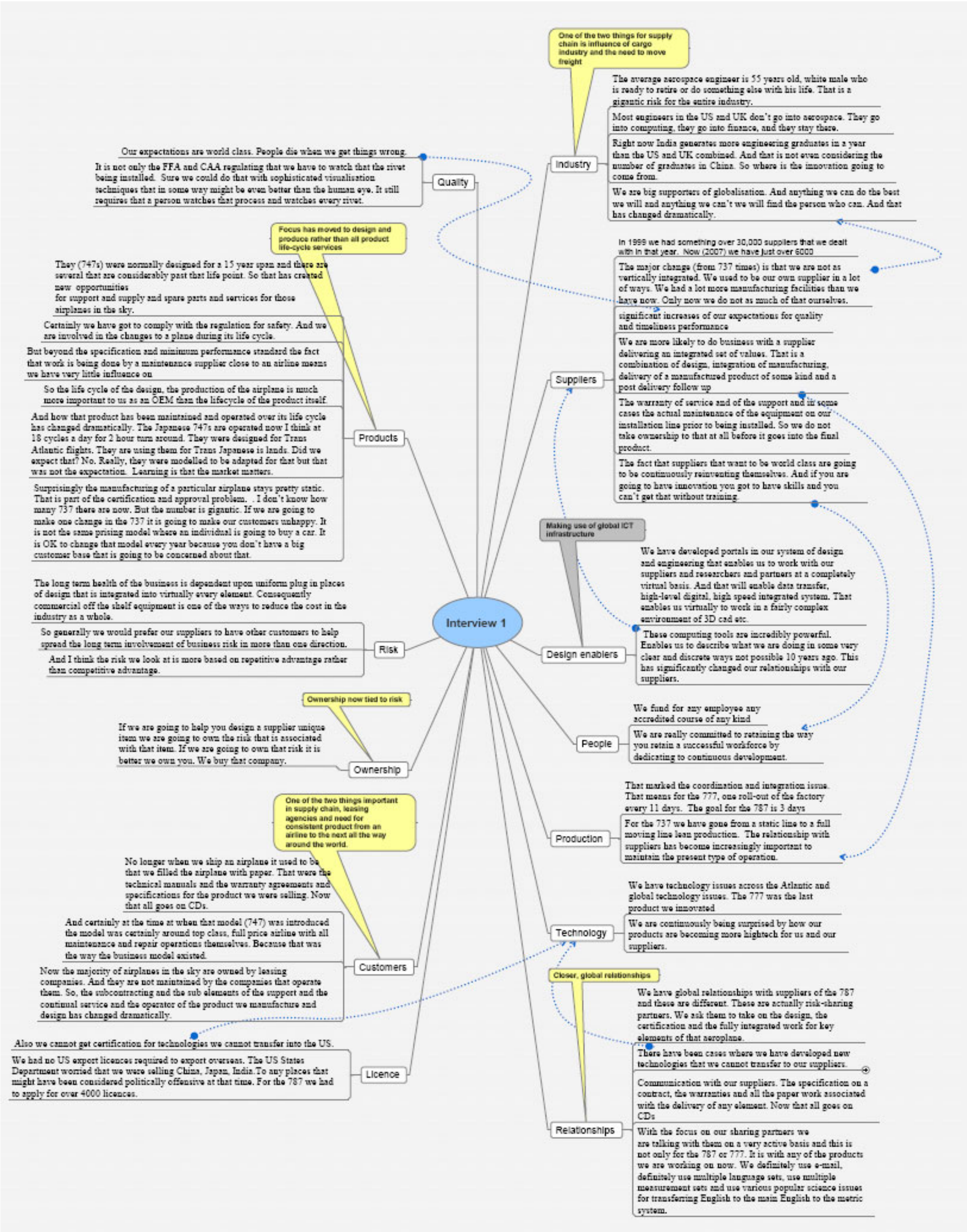
Method	Purpose	Issues	Validity	Limitations
Cladistics This method establishes the underlying characteristics that lead to emergent capabilities of their particular organisational forms. Key concepts, practices and characteristics are located from interview, literature review, or any other source. Characteristics are grouped by 1. time period and/or 2. synergy of characteristics using a pair-wise matrix comparing each to each other	**Used to identify the evolutionary paths along which similar organizations may have evolved and to locate current forms of organization (or other socio-economic group)** The Cladogram is plotted using software, such as MacGlade but can be drawn manually, appearing a little like an inverted dendrogram. Three types of information are shown. 1. The characteristics which were relevant to particular forms of organization at the point of bifurcation 2. The bifurcations which occur when there is a two way division of some set of characteristics, following the 'invasion' of new characteristics thus showing the occurrence of successive new practices and innovative ideas 3. The forms of organization in existence in the current time period. Each organisational form can be understood as a particular "bundle" of internal working practices and rules, which confer on it its particular capabilities and operational abilities. The analysis of these structures allowed the construction of a cladistic diagram showing the major branching points when qualitatively different capabilities emerged.	Issues with the Cladistics method include: • characteristics that replace one or more previous characteristics are not easily recognised • an existing characteristic can appear in a new bundle when it previously bundled with others • literature review information is not always clear concerning the time period to which the characteristics applied • relevant characteristics may be missing from the literature • multiple interpretations of characteristics are possible, particularly if they are generic terms which have not been closely defined and/or if a pair-wise matrix has not been employed or has produced ambiguous results	All relevant articles should be included using systematic methods for their identification. These can identify characteristics that: are not relevant for the industry in question and requires researcher intervention. Alternatively, single source historical accounts of an industry can be used, but these may reflect limited views. The use of multiple researchers avoids single interpretations of the data. The method is based in organizational systematics (McKelvey, 1982; 1994). Examples from manufacturing include: McCarthy (1995) 995; McCarthy et al (1997b); (McCarthy et al., 1997a)Baldwin et al (2005). The output can be of great value to companies in saving them from costly experiments and unsuccessful attempts at strategic change. All innovative technologies face institutional, psychological and economic barriers during their generation and adoption including uncertainty about relative benefits; high start up costs; uncertain and unevenly distributed benefits and risks; path dependency; and, other forms of lock-in.	Limitations of Cladistics for Organization Studies analyses: • evolutionary paths which may have occurred are not shown. • empirical evidence is limited by people's memories when written records are not available • prediction is limited only to the next layer of the evolutionary tree; the time period of the next layer is not predictable • the process, as in case survey, is time consuming and requires resources

B.3 Classification using Repertory Grid Technique

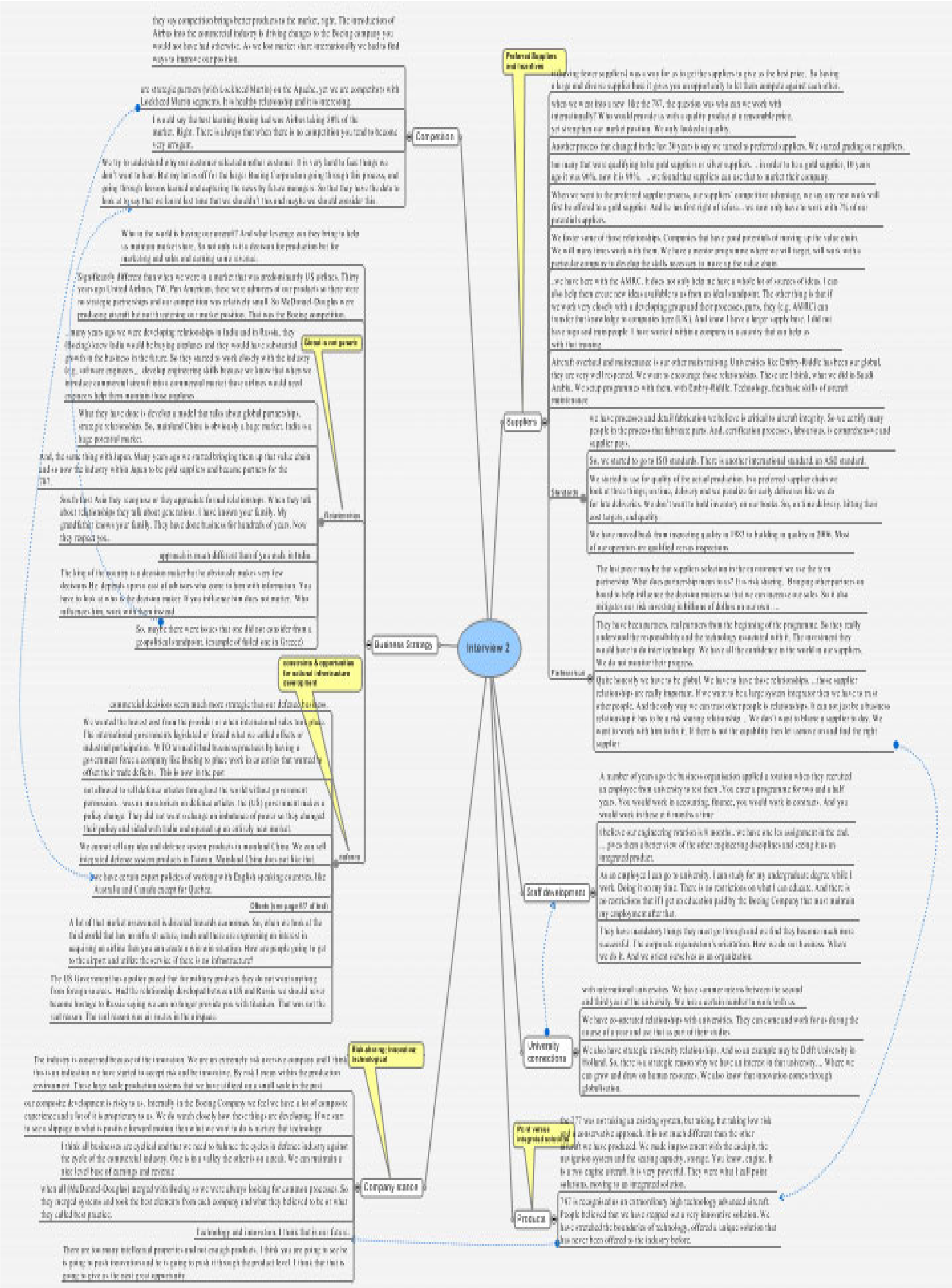
Method	Purpose	Issues	Validity	Limitations
Repertory Grid Technique This research method collects primary data. It involves structured interviews of individuals with access to specific knowledge within organizations. A Repertory Grid is completed, that identifies the bi-polar constructs which the individual uses to make sense of the research topic. The interviewee then rates the constructs. Qualitative analyses and quantitative analyses are possible on the interview data. Many software products are available for numerical analyses of repertory grids, although SPSS can be used for this too. Comparative techniques can be used where multiple repertory grids are available. Note that Repertory Grid Technique can be used on any research topic and is widely used in organization studies	**Used to identify underlying patterns in constructs that individuals use to describe particular organizational settings.** The differentiators between suppliers (or customer) are identified, consolidated and ranked in order of importance. The differentiators which have the greatest variance are identified. Clusters of similar suppliers (or customers) are identified as are clusters of similar differentiators. The differentiators are readily identified using a structured approach which introduces no researcher bias. Some of the differentiators identified by respondents come as a surprise to the respondent as they may reflect tacit understanding that has never before been made explicit. These differentiators are often not found using regular research methods.	Conversely, suppliers (and customers) may be invited to evaluate the organization using the differentiators. This helps the organization to understand how it is perceived by suppliers (and customers) and can be an invaluable driver for change. The alignment (or lack of) between customer and supplier differentiators is identified. These will inform intra (within) organizational decision-making. Examination of past and future customer and supplier portfolios, and the relevant change in the mix of the differentiators will indicate potential opportunities for the organization in preparation for exploiting changes in strategic direction.	The consistency between the relative importance (ranking) of differentiators is also identified. Numerical analyses will identify average scores across respondents, remaining sensitive to the range of different ratings. It can also identify underlying similarities (principal components) which are not obvious by other methods of analysis. Ratings can be explored with each supplier (and similarly with each customer). They describe how your organization views the supplier, for example, with targets, the following chart may apply:	• a lack of support for formal or automatic inferencing and • a lack of general reasoning capabilities beyond heuristic classification. • individual respondents who do not really ‘know’ the objects well enough to differentiate between them. Rep Grids provide a personal view of complex situations. Generalisability must therefore always be limited.

APPENDIX C – Mind Maps

C.1 Mind Map for Prime 1 Interview

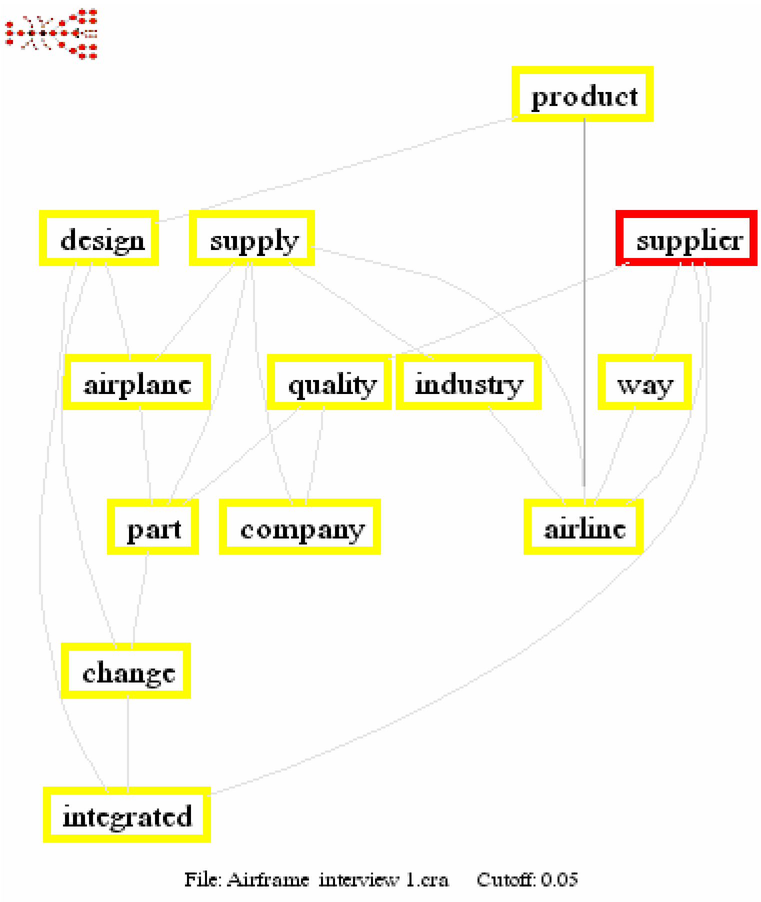


C.2 Mind Map for Prime 2 Interview

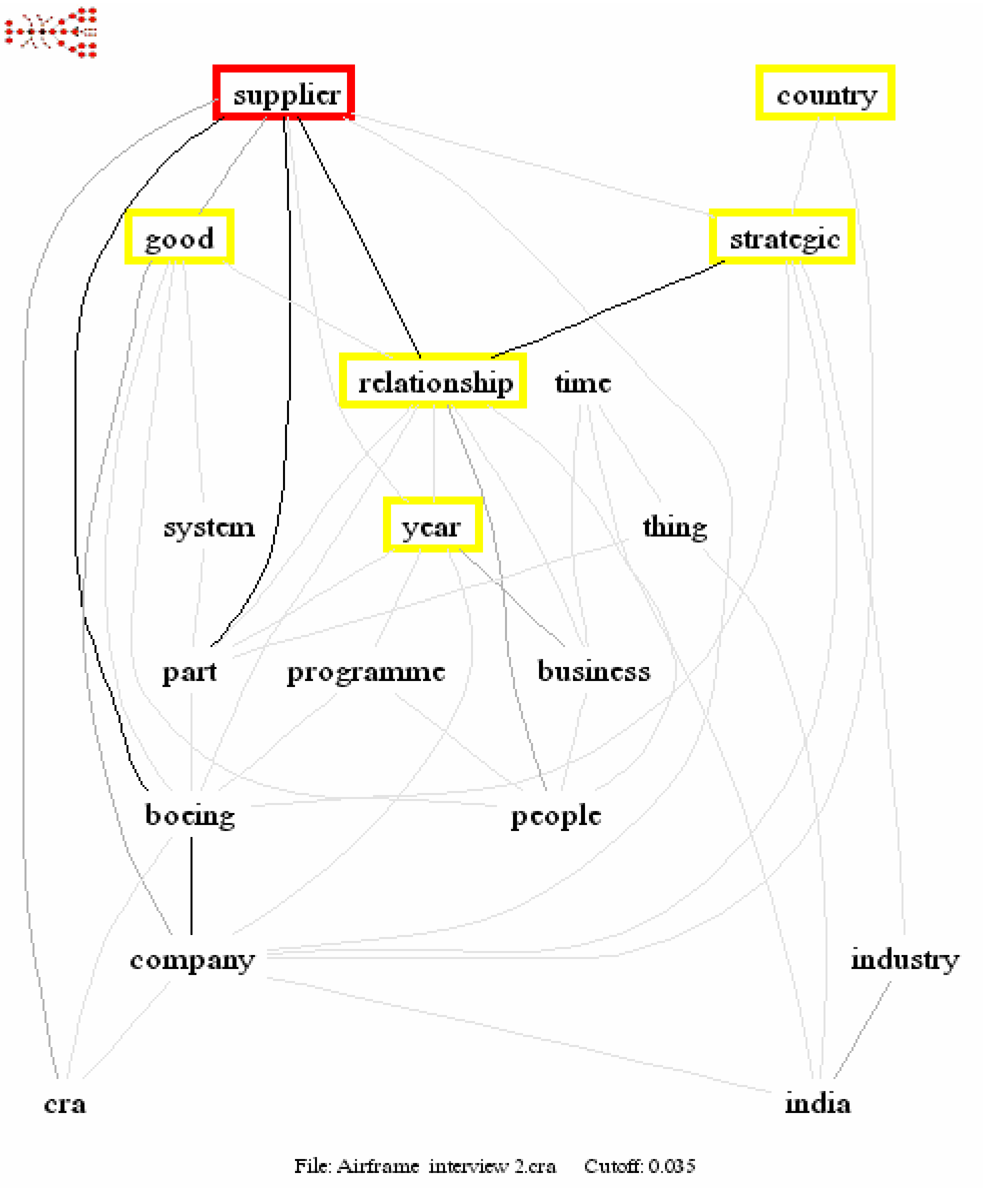


APPENDIX D – CRA Results

D.1 CRAWDAD output for Prime 1 interview transcript



D.2 CRAWDAD output for Prime 2 interview transcript



APPENDIX E – Semi-Structured Interview template

Interviewee

1. Can you please define the scope of your role within {firm deleted} and set it into the context of the organization's evolution and the Supply Chain evolution?

2. How long have you worked in {firm deleted} and in what capacities?

3. Where were you before?

Evolutionary History of the Organization

1. How has the organization evolved in your experience?

    a. Can you recommend any sources of information regarding the history of {firm deleted}?

2. What has been the impact of changes in the last 2 years?

    a. Acquisitions
    b. Leadership changes
    c. Technology changes
    d. Strategy changes (Commerciall/Defence split)
    e. Operational changes (Consolidating manufacturing facilities)
    f. Suppliers changes (LCE)
    g. Supply Chain changes (forming strategic partnership with a smaller number of key suppliers)
        i. What types of relationship?
            1. discrete transactional
            2. repeated transactional
            3. long-term relationships
            4. formal partnerships
    h. Is there creativity in contract negotiation/Risk/reward sharing
    i. Customer changes (Profile of customers)

3. What are the sources of innovation? (examples giving duration and intensity)
    i. Venture Capital to small research firms
    ii. In-house
    iii. University Collaboration
    iv. Customer sourced
    v. Supplier driven
4. Is {firm deleted} a leader in innovation?

5. In terms of a portfolio of products (Boston Consulting Group)

    a. What percentage are Cash Cows
    b. Dogs
    c. Stars
    d. Question Marks?

6. What are the conflicting goals?
    a. Resources – to exploit or to explore
    b. Price – reduced cost but maintained quality
    c. Other?

7. Are there dependencies between the different goals?

8. Are efforts to integrate successful? Why/why not?

9. Are 'components' created that can be re-used as building blocks in other divisions?

10. How is feedback dealt with?
    a. Supplier
    b. Production
    c. Finance
    d. Customer
    e. Other?

Evolutionary History of the Supply Chain

1. What is the character of the Supply Chain at {firm deleted}?
    a. How has the character of the supply chain changed over the last 6 years?
    b. What were the significant changes? Why were they significant?
        i. Responsiveness/Agility
        ii. Batch to Flow
    c. How are customer/market demands for customisation/individuality affecting the Supply Chain
    d. Is the Supply Chain perceived of an organization?
    e. What Supply Chain processes have been developed?

2. What types of business conditions exist?

	Complex	Simple
Volume	Low	High
Product Variety	High	Low
Batches	Small	Large
Made to	Order	Stock
Delivery time	Long	Short
Supplier focus	Flexible	Cost

   a. Is JIT as an integrative practice appropriate only for simple business conditions?
   b. Do more complex products, need more outsourcing (to get the best expertise)?

3. What types of integration exist with suppliers?
   a. What IT systems are integrated?
      i. Communication
      ii. Ordering
      iii. Billing
   b. Is intra-company integration a pre-requisite for Inter-company integration?
4. How are the decisions about whether to outsource or not made?
   a. Is there a strategy?
   b. What are the core competences which will ensure success tomorrow?
   c. How are the boundaries of the Supply Chain being stretched?
      i. Process
      ii. Technology
      iii. Products
   d. What are the perceived vulnerabilities of outsourcing?
      i. Single source or few suppliers in the supply market? (superior knowledge and power)
      ii. Costs of co-ordination?
      iii. Costs of logistics?
      iv. Costs of integration?
      v. Costs of miscommunication?
      vi. Suppliers located in different time zones, different cultures
      vii. Are risks considered only with adjacent tiers?
   e. What are the perceived benefits?
      i. Learning from each other?
      ii. Do you learn only from adjacent tiers?
      iii. Is there knowledge creation facilitation?

    f. Lean and agile methods suggest openness and visibility between tiers? Does this happen?

5. Do {firm deleted} have open/transparent relationships with Customers and Suppliers?

6. How are multiple supply chains dealt with?
    a. Civil and Defence selection environments are different
    b. Do the same suppliers or in-house manufacturing prepare components for aerospace and non-aerospace?
    c. How are these differentiated? Timescale? Volume?

7. As a first-tier supplier, are customer alliances important?
    a. What about customer allegiance?

8. How does your competition deal with the supply chain?
    a. Global/Local
    b. How are they different from {firm deleted}?
    c. How do {firm deleted} stay ahead of the competition?

9. Do any of your suppliers supply your competitors?
    a. Is this OK?
    b. Are there components that they make for your competitors?
    c. Are they learning from what you specify and passing on that learning in the products that they produce?
    d. How do you ensure delivery?

End of interview

Anything interviewee wants to add?
Anything important missed?
Thanks!

APPENDIX F – General Purpose Scheme for Repertory Grid Triads

No of elements	No of triads	No of times each element is compared	Triads (element numbers) Cells marked (*) identify 'fair' schemes in which every element is compared against every other element an equal number of time
6	4	2	1, 3, 5; 1, 4, 6; 2, 4, 5; 2, 3, 6
7	7	3	* 1, 3, 5; 1, 4, 6; 2, 4, 5; 1, 2, 7; 5, 6, 7; 2, 3, 6; 3, 4, 7
8	8	3	1, 3, 5; 1, 7, 8; 3, 4, 8; 4, 5, 6; 6, 7, 8; 2, 5, 7; 2, 3, 6; 1, 2, 4
9	9	3	1, 3, 5; 1, 7, 8; 3, 7, 9; 4, 6, 7; 2, 3, 6; 1, 2, 4; 2, 5, 9; 6, 8, 9; 4, 5, 8
9	12	4	* 1, 3, 7; 1, 5, 8; 2, 5, 7; 6, 7, 8; 2, 8, 9; 4, 7, 9; 4, 5, 6; 1, 6, 9; 2, 3, 6; 1, 2, 4; 3, 4, 8; 3, 5, 9
10	10	3	1 3 4; 2 4 5; 3 5 6; 4 6 7; 5 7 8; 6 8 9; 7 9 10; 1 8 10; 1 2 9; 2 3 10
11	11	3	1, 3, 5; 5, 6, 10; 2, 4, 6; 3, 6, 9; 3, 7, 10; 2, 8, 10; 4, 5, 8; 8, 9, 11; 1, 4, 11; 1, 7, 9; 2, 7, 11
12	12	3	1, 3, 5; 1, 7, 12; 5, 9,12; 8, 9, 11; 1, 4, 11; 4, 5, 8; 2, 8, 10; 6, 10, 12; 3, 7, 10; 2, 7, 11; 2, 4, 6; 3, 6, 9

APPENDIX G – Repertory Grid Interview Supplementary

1. Post title and organization position?

2. Can you please say a little about your background?

3. SC description – mechanical/ electronic/ box-build/ software
   a. Life-cycle point
      a. A new or developing product/system (early life)
      b. A maturing or sales growth system (mid life)
      c. A mature or declining sales system (end life)
   b. Context – growing, declining
   c. SC future – LCE, collaboration, outsourcing, future technologies

4. Which suppliers?

Supplier Name/Pseudonym	**Role**	**Incumbency**	**Criticality**	**Member of other SC?**

Minimum of 6 – preferably as many as 10

APPENDIX H – Blank Table I of Questionnaire Survey Instrument

Characteristics	Success criteria factors					Other
Rate of characteristic to successfactor criteria High (9), None ())	Product quality	Cost efficiency	Delivery precision	Techn./ innovation	Vision for the future	
1. Outsourcing competitive advantage						
2. Outsourcing what is easily imitated						
3. High level of collaborative relationship						
4. Arms length relationships						
5. Long-term relationship						
6. Formal partnership						
7. Subcontracting whole systems and sections						
8. Flexibility of operations						
9. Risk-sharing						
10. Sharing knowledge						
11. Offsets as part of sales contract						
12. Culture of continuous improvement						
13. Ability to handle cutural differences						
14. High level of dominance over supplier						
15. High level of planning and control						
16. Easy dialogue with supplier						
17. IT system integration						
18. High levels of integration of chain						
19. Responsive to market change						
20. Transparent organisation						
21. TQM procedures						
22. Just-in-time delivery						
23. Lean practice						
24. Explorative learning practices						
25. Investment in training						
26. Supplier development						
27. Monitoring supplier						

APPENDIX I – Blank Table II of Questionnaire Survey Instrument

Characteristics	1. Outsourcing competitive advantage	2. Outsourcing what is easily imitated	3. High level of collaborative relationship	4. Arms length relationship	5. Long-term relationship	6. Formal partnership	7. Subcontracting whole systems and sections	8. Flexibility of operations	9. Risk-sharing	10. Sharing knowledge	11. Offsets as part of sales contract	12. Culture of continuous improvement	13. Ability to handle cultural differences	14. High level of dominance over supplier	15. High level of planning and control	16. Easy dialogue with supplier	17. IT system intergration	18. High levels of integration in chain	19. Responsive to market change	20. Transparent organisation	21. TQM procedures	22. Just-in-time delivery	23. Lean practices	24. Explorative learning practices	25. Investment in training	26. Supplier development
Strongly synergetic (+5), indifferent effects (0), strongly conflicting (-5)																										
2. Outsourcing what is easily imitated																										
3. High level of collaborative relationship																										
4. Arms length relationship																										
5. Long-term relationship																										
6. Formal partnership																										
7. Subcontracting whole systems and sections																										
8. Flexibility of operations																										
9. Risk-sharing																										
10. Sharing knowledge																										
11. Offsets as part of sales contract																										
12. Culture of continuous improvement																										
13. Ability to handle cultural differences																										
14. High level of dominance over supplier																										
15. High level of planning and control																										
16. Easy dialogue with supplier																										
17. IT system integration																										
18. High levels of integration in chain																										
19. Responsive to market change																										
20. Transparent organisation																										
21. TQM procedures																										
22. Just-in-time delivery																										
23. Lean practices																										
24. Explorative learning practices																										
25. Investment in training																										
26. Supplier development																										
27. Monitoring suppliers																										

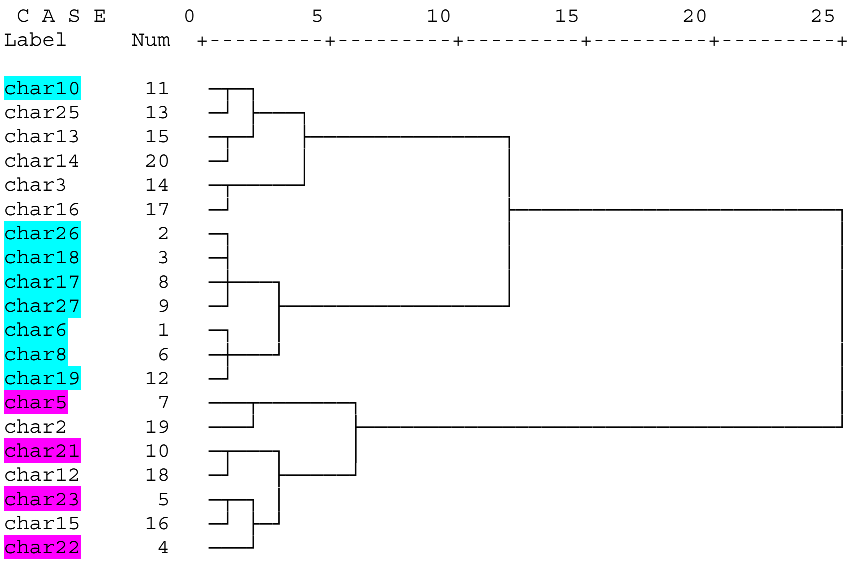
APPENDIX J – Split Half Results

J.1 Means for Data Set 3 (Delivery – First Order)

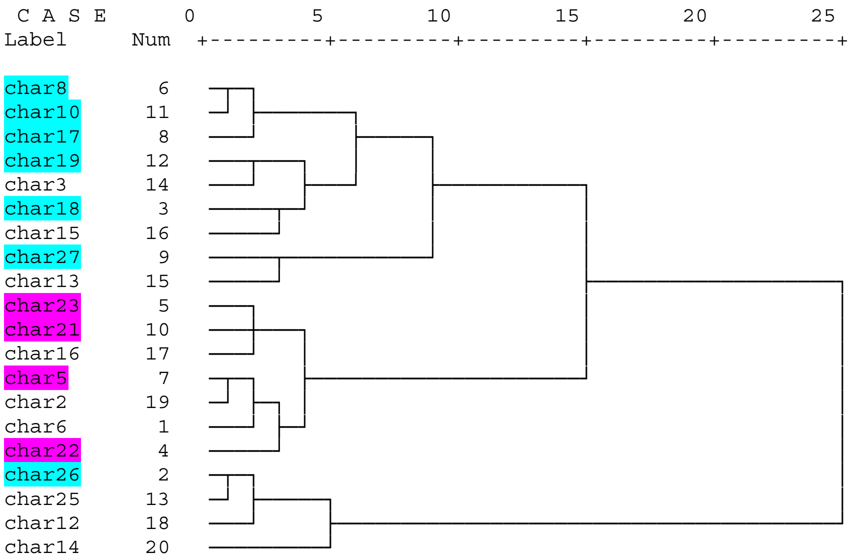
	MEANS		
Data Set	**Split Half 1 - Cluster 1**	**Split Half 1 - Cluster 2**	
1.101	1.007	1.390	
	Split Half 2 - Cluster 1	**Split Half 2 - Cluster 2**	**Split Half 2 - Cluster 3**
	1.038	1.150	0.958

J.2 First Split Half – Data Set 3

KEY: Characteristic belongs to Cluster 1 in full data set, and Cluster 2 in full data set



J.3 Second Split Half – Data Set 3



APPENDIX K – Detailed Analysis Process for Pair-Wise Table II

1. Source data cells are copied into a spreadsheet as shown below

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1																											
2	0	3. High level of collaborative relationship																									
3	4	0	4. Arms length relationship																								
4	0	0	-5	5. Long-term relationship																							
5	2	0	4	-3	6. Formal partnership																						
6	2	0	4	0	4	7. Subcontracting whole systems and sections																					
7	5	0	5	-3	4	0	8. Flexibility of operations																				
8	1	0	0	0	0	0	2	9. Risk-sharing																			
9	4	0	4	-2	4	4	4	0	10. Sharing knowledge																		
10	2	0	4	-4	4	0	4	0	3	11. Offsets as part of sales contract																	
11	0	0	0	0	0	3	0	0	0	0	12. Culture of continuous improvement																
12	2	2	2	0	3	0	0	3	0	0	0	13. Ability to handle cultural differences															
13	1	0	3	0	2	0	0	0	2	2	0	1	14. High level of dominance over supplier														
14	-4	2	-4	0	-3	0	0	0	-3	0	0	0	-4	15. High level of planning and control													
15	3	0	0	0	0	2	0	2	0	0	0	0	0	0	16. Easy dialogue with supplier												
16	2	0	2	0	2	1	0	0	0	4	0	2	3	-3	0	17. IT system intergration											
17	1	0	2	0	2	1	3	2	0	4	0	0	0	0	3	0	18. High levels of integration in chain										
18	0	0	1	-3	2	1	3	0	3	1	3	0	0	0	1	0	1	19. Responsive to market change									
19	2	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	20. Transparent organisation								
20	2	0	2	0	5	1	0	0	0	4	0	2	3	0	0	3	0	0	1	21. TQM practices							
21	2	3	1	0	0	0	3	3	0	0	0	3	0	0	3	0	0	0	2	0	22. Just-in-time delivery						
22	2	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	2	0	1	23. Lean practices					
23	2	0	0	0	0	0	0	4	0	0	0	2	0	0	2	0	0	0	2	0	2	2	24. Explorative lea				
24	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	25. Investmer			
25	1	0	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	2	2	26. Supp		
26	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0		
27	2	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	3	

2. The values are copied into a new matrix (in order to allow the process to be repeated for many pair-wise source data). The diagonal is zeroised.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	0																										
2	0	0																									
3	4	0	0																								
4	0	0	-5	0																							
5	2	0	4	-3	0																						
6	2	0	4	0	4	0																					
7	5	0	5	-3	4	0	0																				
8	1	0	0	0	0	0	2	0																			
9	4	0	4	-2	4	4	4	0	0																		
10	2	0	4	-4	4	0	4	0	3	0																	
11	0	0	0	0	0	3	0	0	0	0	0																
12	2	2	2	0	3	0	0	3	0	0	0	0															
13	1	0	3	0	2	0	0	0	2	2	0	1	0														
14	-4	2	-4	0	-3	0	0	0	-3	0	0	0	-4	0													
15	3	0	0	0	0	2	0	2	0	0	0	0	0	0	0												
16	2	0	2	0	2	1	0	0	0	4	0	2	3	-3	0	0											
17	1	0	2	0	2	1	3	2	0	4	0	0	0	0	3	0	0										
18	0	0	1	-3	2	1	3	0	3	1	3	0	0	0	1	0	1	0									
19	2	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0								
20	2	0	2	0	5	1	0	0	0	4	0	2	3	0	0	3	0	0	1	0							
21	2	3	1	0	0	0	3	3	0	0	0	3	0	0	3	0	0	0	2	0	0						
22	2	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	2	0	1	0					
23	2	0	0	0	0	0	0	4	0	0	0	2	0	0	2	0	0	0	2	0	2	2	0				
24	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0			
25	1	0	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	2	2	0		
26	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	
27	2	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0

3. The matrix from step 2 is copied with Paste Special – Values - into a new matrix. This step is required because the transpose function fails without it.
4. The matrix from step 3 is copied with Paste Special – Transpose – into a new matrix shown to the right of the figure below.

0																										
0	0																									
4	0	0																								
0	0	-5	0																							
2	0	4	-3	0																						
2	0	4	0	4	0																					
5	0	5	-3	4	0	0																				
1	0	0	0	0	0	2	0																			
4	0	4	-2	4	4	4	0	0																		
2	0	4	-4	4	0	4	0	3	0																	
0	0	0	0	0	3	0	0	0	0	0																
2	2	2	0	3	0	0	3	0	0	0	0															
1	0	3	0	2	0	0	0	2	2	0	1	0														
-4	2	-4	0	-3	0	0	0	-3	0	0	0	-4	0													
3	0	0	0	0	2	0	2	0	0	0	0	0	0	0												
2	0	2	0	2	1	0	0	0	4	0	2	3	-3	0	0											
1	0	2	0	2	1	3	2	0	4	0	0	0	0	3	0	0										
0	0	1	-3	2	1	3	0	3	1	3	0	0	0	1	0	1	0									
2	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0								
2	0	2	0	5	1	0	0	0	4	0	2	3	0	0	3	0	0	1	0							
2	3	1	0	0	0	3	3	0	0	0	3	0	0	3	0	0	0	2	0	0						
2	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	2	0	1	0					
2	0	0	0	0	0	0	4	0	0	0	2	0	0	2	0	0	0	2	0	2	2	0				
1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0			
1	0	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	2	2	0		
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	
2	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0

0	0	4	0	2	2	5	1	4	2	0	2	1	-4	3	2	1	0	2	2	2	2	2	1	1	1	2
	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	3	0	0	0	0	0	0
		0	-5	4	4	5	0	4	4	0	2	3	-4	0	2	2	1	1	2	1	0	0	0	1	0	0
			0	-3	0	-3	0	-2	-4	0	0	0	0	0	0	0	-3	0	0	0	0	0	0	0	0	0
				0	4	4	0	4	4	0	3	2	-3	0	2	2	2	0	5	0	0	0	0	0	0	0
					0	0	0	4	0	3	0	0	0	2	1	1	1	0	1	0	0	0	0	0	0	1
						0	2	4	4	0	0	0	0	0	0	3	3	0	0	3	0	0	0	0	0	0
							0	0	0	0	3	0	0	2	0	2	0	0	0	3	2	4	0	0	0	0
								0	3	0	0	2	-3	0	0	0	3	0	0	0	0	0	0	0	0	0
									0	0	0	2	0	0	4	4	1	0	4	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
											0	1	0	0	2	0	0	2	2	3	0	2	0	4	0	2
												0	-4	0	3	0	0	0	3	0	0	0	2	0	0	0
													0	0	-3	0	0	0	0	0	0	0	0	0	0	0
														0	0	3	1	0	0	3	2	2	0	0	0	0
															0	0	0	0	3	0	0	0	0	0	0	0
																0	1	0	0	0	0	0	0	0	0	0
																	0	0	0	0	0	0	0	0	2	0
																		0	1	2	2	2	0	0	0	0
																			0	0	0	0	0	0	0	0
																				0	1	2	2	0	2	0
																					0	2	0	0	0	2
																						0	0	2	0	0
																							0	2	0	0
																								0	0	0
																									0	3
																										0

5. A new matrix is then formed by copying the cells from the two halves in step 4 EXCEPT that the formula ABS from Excel is used to ignore the sign of the cells in the transposed matrix (to the right of the diagonal).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	0	0	4	0	2	2	5	1	4	2	0	2	1	4	3	2	1	0	2	2	2	2	2	1	1	1	2
2	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	3	0	0	0	0	0	0
3	4	0	0	5	4	4	5	0	4	4	0	2	3	4	0	2	2	1	1	2	1	0	0	0	1	0	0
4	0	0	-5	0	3	0	3	0	2	4	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
5	2	0	4	-3	0	4	4	0	4	4	0	3	2	3	0	2	2	2	0	5	0	0	0	0	0	0	0
6	2	0	4	0	4	0	0	0	4	0	3	0	0	0	2	1	1	1	0	1	0	0	0	0	0	0	1
7	5	0	5	-3	4	0	0	2	4	4	0	0	0	0	0	0	3	3	0	0	3	0	0	0	0	0	0
8	1	0	0	0	0	0	2	0	0	0	0	3	0	0	2	0	2	0	0	0	3	2	4	0	0	0	0
9	4	0	4	-2	4	4	4	0	0	3	0	0	2	3	0	0	0	3	0	0	0	0	0	0	0	0	0
10	2	0	4	-4	4	0	4	0	3	0	0	0	2	0	0	4	4	1	0	4	0	0	0	0	0	0	0
11	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
12	2	2	2	0	3	0	0	3	0	0	0	0	1	0	0	2	0	0	2	2	3	0	2	0	4	0	2
13	1	0	3	0	2	0	0	0	2	2	0	1	0	4	0	3	0	0	0	3	0	0	0	2	0	0	0
14	-4	2	-4	0	-3	0	0	0	-3	0	0	0	-4	0	0	3	0	0	0	0	0	0	0	0	0	0	0
15	3	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	3	1	0	0	3	2	2	0	0	0	0
16	2	0	2	0	2	1	0	0	0	4	0	2	3	-3	0	0	0	0	0	3	0	0	0	0	0	0	0
17	1	0	2	0	2	1	3	2	0	4	0	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	0
18	0	0	1	-3	2	1	3	0	3	1	3	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2	0
19	2	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	2	2	2	0	0	0	0
20	2	0	2	0	5	1	0	0	0	4	0	2	3	0	0	3	0	0	1	0	0	0	0	0	0	0	0
21	2	3	1	0	0	0	3	3	0	0	0	3	0	0	3	0	0	0	2	0	0	1	2	2	0	2	0
22	2	0	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	2	0	1	0	2	0	0	0	2
23	2	0	0	0	0	0	0	4	0	0	0	2	0	0	2	0	0	0	2	0	2	2	0	0	2	0	0
24	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	2	0	0
25	1	0	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
26	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	3
27	2	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0

6. The matrix from step 5 is copied twice with Paste Special – Values – as above, to avoid problems with formulas. The two matrices form the source matrices to the matrix multiplication calculation.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	0	4	4	5	5	5	3	4	5	5	0	5	0	5	4	4	0	5	4	4	0	0	5	5	3	4	4
2	4	0	4	2	4	3	3	4	3	0	4	1	0	2	2	3	0	3	3	2	3	5	4	2	3	3	3
3	-4	4	0	5	5	4	5	3	5	5	0	5	3	5	3	5	3	5	4	5	3	3	5	5	4	4	2
4	-5	2	-5	0	1	5	3	2	5	5	0	3	0	2	2	2	3	2	0	4	3	0	0	4	5	4	3
5	5	4	5	-1	0	5	4	3	3	5	0	4	4	0	4	4	0	3	0	2	0	0	2	4	3	3	2
6	5	3	4	-5	5	0	4	2	5	3	3	3	3	5	4	3	3	4	0	2	3	0	3	4	3	4	1
7	3	3	5	-3	4	4	0	4	0	2	0	0	0	0	4	0	0	2	2	0	0	0	0	3	2	0	4
8	4	4	3	-2	-3	-2	-4	0	4	4	3	5	4	3	2	4	4	3	5	3	3	4	5	4	4	3	3
9	5	-3	5	-5	3	5	0	-4	0	5	2	3	0	5	3	4	0	0	3	3	0	0	4	4	3	4	2
10	5	0	5	-5	5	3	-2	4	5	0	0	0	5	4	0	5	0	4	4	5	0	4	5	5	3	4	1
11	0	4	0	0	0	3	0	-3	2	0	0	1	1	0	0	0	0	2	3	0	0	3	3	3	2	4	4
12	-5	-1	5	-3	4	3	0	5	3	0	-1	0	5	4	0	5	4	2	3	3	2	4	5	5	4	4	3
13	0	0	3	0	4	3	0	4	0	5	1	5	0	0	0	5	1	3	0	3	0	1	4	5	3	3	0
14	5	-2	-5	2	0	-5	0	-3	-5	-4	0	-4	0	0	4	2	4	0	5	3	0	0	2	3	3	3	5
15	4	2	3	2	-4	-4	-4	-2	-3	0	0	0	0	4	0	1	3	3	2	0	0	2	2	0	3	4	5
16	4	3	5	-2	4	3	0	4	4	5	0	5	5	2	-1	0	2	2	3	5	0	3	4	5	3	4	3
17	0	0	3	-3	0	3	0	-4	0	0	0	-4	1	4	3	-2	0	4	4	2	3	2	4	4	0	0	3
18	5	3	5	-2	3	4	2	3	0	4	2	2	3	0	3	2	4	0	3	4	3	5	5	5	4	5	0
19	-4	3	4	0	0	0	-2	5	-3	4	-3	3	0	-5	2	-3	-4	3	0	5	1	4	5	4	4	5	0
20	4	2	5	-4	2	2	0	3	3	5	0	3	3	-3	0	5	2	4	5	0	3	4	5	4	4	4	5
21	0	3	3	-3	0	3	0	-3	0	0	0	2	0	0	0	0	3	3	1	3	0	3	4	2	3	4	2
22	0	5	3	0	0	0	0	4	0	4	-3	4	1	0	2	3	-2	5	4	4	3	0	5	3	3	4	2
23	-5	4	5	0	2	3	0	5	4	5	-3	5	4	2	-2	4	-4	5	5	5	4	5	0	5	4	5	1
24	5	-2	5	-4	4	4	3	4	4	5	3	5	5	-3	0	5	-4	5	4	4	2	3	5	0	4	5	2
25	-3	3	4	-5	3	3	-2	4	3	3	2	4	3	-3	3	3	0	4	4	4	3	3	4	4	0	4	0
26	4	3	4	-4	3	4	0	3	4	4	4	4	3	-3	4	4	0	5	5	4	4	4	5	5	4	0	0
27	4	3	2	-3	2	1	4	3	2	1	4	3	0	5	5	3	3	0	0	5	2	2	1	2	0	0	0

1	0	4	4	5	5	5	3	4	5	5	0	5	0	5	4	4	0	5	4	4	0	0	5	5	3	4	4
2	4	0	4	2	4	3	3	4	3	0	4	1	0	2	2	3	0	3	3	2	3	5	4	2	3	3	3
3	-4	4	0	5	5	4	5	3	5	5	0	5	3	5	3	5	3	5	4	5	3	3	5	5	4	4	2
4	-5	2	-5	0	1	5	3	2	5	5	0	3	0	2	2	2	3	2	0	4	3	0	0	4	5	4	3
5	5	4	5	-1	0	5	4	3	3	5	0	4	4	0	4	4	0	3	0	2	0	0	2	4	3	3	2
6	5	3	4	-5	5	0	4	2	5	3	3	3	3	5	4	3	3	4	0	2	3	0	3	4	3	4	1
7	3	3	5	-3	4	4	0	4	0	2	0	0	0	0	4	0	0	2	2	0	0	0	0	3	2	0	4
8	4	4	3	-2	-3	-2	-4	0	4	4	3	5	4	3	2	4	4	3	5	3	3	4	5	4	4	3	3
9	5	-3	5	-5	3	5	0	-4	0	5	2	3	0	5	3	4	0	0	3	3	0	0	4	4	3	4	2
10	5	0	5	-5	5	3	-2	4	5	0	0	0	5	4	0	5	0	4	4	5	0	4	5	5	3	4	1
11	0	4	0	0	0	3	0	-3	2	0	0	1	1	0	0	0	0	2	3	0	0	3	3	3	2	4	4
12	-5	-1	5	-3	4	3	0	5	3	0	-1	0	5	4	0	5	4	2	3	3	2	4	5	5	4	4	3
13	0	0	3	0	4	3	0	4	0	5	1	5	0	0	0	5	1	3	0	3	0	1	4	5	3	3	0
14	5	-2	-5	2	0	-5	0	-3	-5	-4	0	-4	0	0	4	2	4	0	5	3	0	0	2	3	3	3	5
15	4	2	3	2	-4	-4	-4	-2	-3	0	0	0	0	4	0	1	3	3	2	0	0	2	2	0	3	4	5
16	4	3	5	-2	4	3	0	4	4	5	0	5	5	2	-1	0	2	2	3	5	0	3	4	5	3	4	3
17	0	0	3	-3	0	3	0	-4	0	0	0	-4	1	4	3	-2	0	4	4	2	3	2	4	4	0	0	3
18	5	3	5	-2	3	4	2	3	0	4	2	2	3	0	3	2	4	0	3	4	3	5	5	5	4	5	0
19	-4	3	4	0	0	0	-2	5	-3	4	-3	3	0	-5	2	-3	-4	3	0	5	1	4	5	4	4	5	0
20	4	2	5	-4	2	2	0	3	3	5	0	3	3	-3	0	5	2	4	5	0	3	4	5	4	4	4	5
21	0	3	3	-3	0	3	0	-3	0	0	0	2	0	0	0	0	3	3	1	3	0	3	4	2	3	4	2
22	0	5	3	0	0	0	0	4	0	4	-3	4	1	0	2	3	-2	5	4	4	3	0	5	3	3	4	2
23	-5	4	5	0	2	3	0	5	4	5	-3	5	4	2	-2	4	-4	5	5	5	4	5	0	5	4	5	1
24	5	-2	5	-4	4	4	3	4	4	5	3	5	5	-3	0	5	-4	5	4	4	2	3	5	0	4	5	2
25	-3	3	4	-5	3	3	-2	4	3	3	2	4	3	-3	3	3	0	4	4	4	3	3	4	4	0	4	0
26	4	3	4	-4	3	4	0	3	4	4	4	4	3	-3	4	4	0	5	5	4	4	4	5	5	4	0	0
27	4	3	2	-3	2	1	4	3	2	1	4	3	0	5	5	3	3	0	0	5	2	2	1	2	0	0	0
27	2	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0

7. The Matrix Multiplication formula MMULT from Excel is used. The output matrix (27x27 cells) is marked and then the two input matrices are selected. The initial outcome provides a result in only cell (1,1) of the output matrix. The entire output matrix is selected, then F2 pressed, then Ctrl/Shift/Enter pressed, populating all 27x27 in the output matrix.

8. The values in the diagonal are then used for form a new column as shown in the figure below.

164	177	283	-183	173	219	41	150	180	263	75	240	174	90	163	207	71	269	205	254	122	200	303	307	247	297	184	1	164
97	115	242	-150	143	166	36	159	159	200	49	180	147	91	112	186	30	212	184	212	135	174	225	238	207	231	139	2	115
179	210	312	-195	154	185	15	145	153	270	55	245	205	80	173	226	74	293	256	285	141	220	338	338	264	316	186	3	312
117	133	197	-137	88	98	-36	65	58	113	34	122	102	37	97	99	41	139	143	147	54	126	189	181	106	137	69	4	-137
85	109	143	-89	144	161	28	99	123	154	71	142	99	76	134	138	66	178	186	208	103	162	223	240	181	199	149	5	144
107	119	192	-116	153	111	11	131	134	157	81	158	134	122	125	171	98	210	206	247	138	202	281	253	214	255	147	6	111
35	67	86	-67	115	110	33	74	97	120	40	107	52	48	74	71	40	97	91	105	70	83	113	137	109	130	82	7	33
38	94	176	-74	156	168	38	149	102	156	26	145	127	21	75	179	32	212	217	231	129	217	259	237	200	250	135	8	149
66	91	128	-105	96	95	7	94	95	77	70	80	64	28	64	76	58	149	122	110	95	138	145	134	120	139	130	9	95
102	69	182	-157	157	127	25	96	101	125	66	102	94	72	122	145	37	205	196	213	131	174	218	212	187	225	148	10	125
20	77	89	-41	84	69	31	121	77	86	19	97	73	-4	54	90	3	107	90	104	66	98	90	100	77	94	45	11	19
111	87	155	-177	103	109	2	56	69	155	44	116	103	51	126	131	47	167	182	198	116	127	185	203	165	203	117	12	116
46	84	160	-140	122	157	35	68	92	149	60	126	78	36	110	107	20	153	118	156	89	110	178	187	131	160	86	13	78
99	34	98	-42	5	8	28	42	19	25	54	49	50	-53	23	15	19	33	51	34	58	91	70	11	11	38	6	14	-53
-5	43	30	40	10	56	51	63	13	59	13	64	14	-22	28	36	-1	54	38	72	56	89	56	43	62	79	29	15	28
105	107	166	-124	174	165	52	113	127	165	80	169	104	66	131	198	70	201	191	220	120	179	234	244	211	256	145	16	198
-4	83	66	-34	23	13	-23	98	37	67	-19	76	56	-52	11	25	-5	96	84	76	56	87	75	54	83	117	75	17	-5
93	148	212	-139	187	198	74	157	173	212	86	202	145	77	141	206	72	221	232	248	165	202	254	269	225	252	159	18	221
-46	74	45	-73	87	133	62	59	87	155	21	176	36	-39	50	79	-43	91	53	136	46	42	75	101	80	99	12	19	53
61	98	164	-131	173	180	54	139	139	181	57	158	110	27	120	164	5	202	208	218	150	187	233	241	185	224	122	20	218
-10	84	80	-45	85	87	36	116	69	102	28	108	56	-13	53	71	15	104	80	125	79	108	99	105	98	104	37	21	79
47	101	124	-80	100	139	45	71	88	180	36	172	69	5	95	116	2	171	135	176	86	117	198	173	145	177	98	22	117
16	149	134	-124	99	135	4	65	88	187	0	165	76	47	129	153	20	217	177	211	105	120	201	247	177	209	131	23	201
91	73	175	-165	162	151	29	110	128	145	64	133	98	62	120	167	24	207	196	215	125	171	240	245	205	213	158	24	245
-4	80	137	-138	165	146	36	109	99	159	7	136	95	42	81	126	25	160	151	201	93	119	193	212	152	194	100	25	152
31	118	233	-160	220	209	34	184	167	212	33	184	157	31	107	189	19	254	243	256	151	209	295	296	234	267	158	26	267
57	91	178	-76	105	107	-6	75	101	130	40	124	108	125	57	128	92	156	159	169	93	155	208	192	166	198	127	27	127

The outcome of this process is that for each pair-wise matrix, a single column of data is available indicating the inter-characteristic effects for each of the 27 characteristics.

APPENDIX L – TRANSCRIPTS - PRIME

Extracts from transcripts of interviews held at the Prime are presented in this appendix, organized by core category (shown in capital letters in headings) and sub-category. Unbroken quotes indicate one interviewee's words. A series of dots (…) indicates that superfluous text has been removed, which does not add (nor detract) from the points being made. Brackets show text added by the author to aid the reader and are not intended to divert from the words spoken by the interviewee.

GLOBALIZATION: Access to Skills
"The average aerospace engineer is 55 years old, white male who is ready to retire or do something else with his life. That is a gigantic risk for the entire industry. Most engineers {countries deleted} don't go into aerospace. They go into computing, they go into finance, and they stay there. Right now {another country} generates more engineering graduates in a year than the {countries deleted} combined. And that is not even considering the number of graduates in {a third country}. So where is the innovation going to come from? Do they have an educational system in their culture and (a) work ethic that is going to drive it?" "We are big supporters of globalization. And anything we can do the best we will and anything we can't we will find the person who can. The fact that suppliers that want to be world class are going to be continuously reinventing themselves." "The other aspect is that our supply chain (is) somewhat an ingrown industry. We tend to borrow from each other and steal skills. So we will see a lot of turn up in the supply chain as we go up and down. So in other words today we can walk into one of my suppliers and he will be looking for 5 or 6 machinists because they had just got hired at {another firm } for {hourly rate deleted} instead of {hourly rate / 2} they were making at the supplier." "Now, one of the things we have seen …of trades and crafts that there is a skill set shortage. So, a lot of younger people don't want to go into machinist learning. Will rather play with the computers and go into other things. So, I have actually seen some of my suppliers relocate their factories to places like {country deleted}, because they can't get skilled, young people that want to learn how to do the crafts. So we are seeing a migration on skill sets and learning at the lower level of our tier of the supply chain, that is starting to manifest itself in the basic other macro economic factors of the industrial world. So we have to manage that also. Aircraft overhaul and maintenance is our other main training. We set up programmes (for) basic skills of aircraft maintenance with international universities. We have summer interns between the second and third year at the university. We hire a certain number to work with us. We have cooperated with universities. They can come and work for us during the course of a year and use that as part of their studies. We also have strategic university relationships....where we can grow and draw on human resources. We also know that innovation comes through globalization."

GLOBALIZATION: Product Complexity
"Whereas in the early days our supply chain (there) were very few people working together in a single factory using local resources to design and build airplanes. As the airplanes as products and service offerings gotten more and more complex we broadened the network. And now in part driven the complexity of the airplane, but also driven by recognition that there are really smart people and great resources in other parts of the world, our supply chain has gotten broader and more complex. Therefore teaming with many more people and bringing products in to final assembly." "The {jetliner model deleted} were normally designed for a 15 year span and there are several that are considerably past that life point. So that has created new opportunities for support and supply and spare parts and services for those airplanes in the sky. Certainly we have got to comply with the regulation for safety. And we are involved in the changes to a plane during its life cycle." "But beyond the specification and minimum performance standard the fact that work is being done by a maintenance supplier close to an airline means we have very little influence. So the life cycle of the design, the production of the airplane is much more important to us as an OEM than the lifecycle of the product itself."
GLOBALIZATION: Low Cost
"Airlines don't particularly care here we get our parts from. They want a high quality product as inexpensive as we can get it. That is really the driver behind it all… So for instance with the Chinese we had to teach them a lot about quality. But with the Russians we are teaching about schedules. Depending on which part of the world you have got into or what maturity of the supplier you are dealing with depends on how much you have to teach them to be able to be an important supplier to {Prime deleted}. Some of that is a long time commitment. It takes a lot of resources and energy."
GLOBALIZATION: Competition
"Thirty years ago {home airline companies} were admirers of our products so there were no strategic partnerships and our competition was relatively small. So {competitor deleted} were producing aircraft but not threatening our market position. Competition they say competition brings better products to the market, right. The introduction of {competitor deleted} into the commercial industry is driving changes to the {the firm} you would not have had otherwise. As we lost market share internationally we had to find ways to improve our position. I would say the best learning {the firm} had was {competitor name deleted} taking 50% of the market. There is always that when there is no competition you tend to become very arrogant. We try to understand why our customer selected another supplier. It is very hard to face things we don't want to hear. But my hat is off for the {corporation name deleted} going through this process, and going through lessons learned and capturing the news by future managers. So that they have the data to look at to say that we learnt last time that we shouldn't this and maybe we should consider this."
SPECIALIZATION: Consolidation
"That is the other thing we have seen. More and more suppliers take over. We call it

moving up the value streams. Where we used to have 3600 suppliers, now we deal with 900. I think our production system is very evolving that way. So the highest level assemblies and the integration is where we see our core competencies. So that suppliers that have gone out and acquired other suppliers to complement capabilities so that they can produce an assembly or a kit. And we have told them how we want to go. So we have seen that progression. And in some other cases we have acted and physically pulled one out and said; 'you are going to simply do nuts and bolts for us. We don't want you to do anything else'. Some of it is directed, some of it is its own natural evolution." "In 1999 we had something over 30,000 suppliers that we dealt with in that year. Now (2007) we have just over 6000."
SPECIALIZATION: Demand Fluctuation
"It is pretty hard pressed because in most other industries they will take and double its production in less than 3 years. Go from x to 2x in 3 years on a wide range of complexity we have. We have done that. And we have decelerated in that. So when you start looking at your suppliers, one of the things you have to find is that the certain key commodities you have to have them somewhat beholden to you because if you do not have enough work to grab their attention, then they become a liability. If they have too much work they become so much risk so when you go up and you go down the financial risk then causes back to you. So you want to have them diversified. But you want to have them such that they are still beholden to you. So, and get that is a small thing that can hold us up or kill us as we try and get things we need for our production." "It is very interesting how these continually evolving, our `suppliers evolve. I think that is as much a challenge as our suppliers are evolving at the same time. When we go down in rate, they are out diversifying. They say; 'I am not going to be exposed to this Market place any more. I can't stand this up and down with {prime deleted}. We need still to go up and down. We need you to go up and down. For instance I have 2 or 3 times this year where {supplier deleted} calls us up; 'we are going to be out doing this come first of June'. {customer from another industry name deleted} customer is as big as we are. It's very hard to communicate attention for something we buy 50000.00 {currency deleted} worth. But it is critical."
SPECIALIZATION: 2nd tier
"As you move down the tiers you tend to either line up with {competitor name deleted} or its like. They may have some minor Airbus work. You know there is not as much overlap as you think. But there are some critical overlaps. And when you look at for example the engine makers or some of the systems businesses (they) are more tied to the aftermarket. In the airframe (market it) is predominantly the acquisition, it is a very small portion is the aftermarket, inverse for example to an engine."
SPECIALIZATION: Jetliner Ownership
"And certainly at the time at when that model {model deleted} was introduced the model was certainly around top class, full price airline with all maintenance and repair operations themselves. Because that was the way the business model existed. Now the majority of airplanes in the sky are owned by leasing companies. And they are not

maintained by the companies that operate them. So, the subcontracting and the sub elements of the support and the continual service and the operator of the product we manufacture and design has changed dramatically.”
PARTNERSHIP: Vertical Disintegration
“The major change is that we are not as vertically integrated. We used to be our own supplier in a lot of ways. We had a lot more manufacturing facilities than we have now. Only now we do not as much of that ourselves. We are more likely to do business with a supplier delivering an integrated set of values. That is a combination of design, integration of manufacturing, delivery of a manufactured product of some kind and a post-delivery follow up.” “If we are going to help you design a supplier unique item we are going to own the risk that is associated with that item. If we are going to own that risk it is better we own you. We buy that company.”
PARTNERSHIP: New Product Introductions
“I think that our supply chain has been evolving from the standpoint that, if you take a look at different levels of the supply chain, depending on where you are at, the supplier selection model is different. You get at the lower part of the supply chain at the commodity level it is much more competitive, short relationships that are also being evaluated. If you are a large partner then you pretty much marry. When you choose that supplier you pretty much marry to him on that programme. So the supplier selection has evolved, and is almost all up-front. So I mean we essentially take into account market access. We take into account access to capital market, access to technology. We take into account other strategic items. {Prime’s name deleted} says; ‘you need to choose the supplier based on the total enterprise solution. So supplier selection has many different facets to it depending on where you are at in terms of the type of supplier and type of product they are supplying {prime’s name deleted}. “Surprisingly the manufacturing of a particular airplane stays pretty static. That is part of the certification and approval problem. I don’t know how many {product models} there are now. But the number is gigantic. If we are going to make one change in the {product model} it is going to make our customers unhappy. It is not the same pricing model where an individual is going to buy a car. It is OK to change that model every year because you don’t have a big customer base that is going to be concerned about that.” “Long cycle between our product introductions: 10 – 15 years between the time you do the airplane. (To) do that shorter, but you can’t, the whole process of building a new airplane, bringing suppliers on board, both new and existing suppliers on other programmes. (This is) a whole different process than actually them actually ramping up to build a different model of a product in a sustaining mode. And we struggle right now because it just happens to be that our new airplane is coming at a time when we are ramping up our existing product base at the same time. So it is putting a dual requirement on your supply base and new material systems.”
PARTNERSHIP: Quality Management

“(There have been) significant increases of our expectations for quality and timeliness performance. (This includes) the warranty of service and of the support and in some cases the actual maintenance of the equipment on our installation line prior to being installed. So we do not take ownership to that at all before it goes into the final product.”

“But how do you help the supplier to be successful? So you see a lot more sharing. What we have learned, what we have incorporated with the suppliers to make them more efficient or higher quality so that both can get benefit. Before it was very much; ‘you will do this’. I say it had a lot to do with industrial trends, the knowledge. Seeing the automotive industry work, manufacturers that had better production systems for winning, I think it brought a realization to most industries. And so we really started to talk about lean manufacturing and increasing all our awareness to the point now I think most people are pretty well grounded in. And understand fairly well the global industrial trends. And now it’s a matter really of stepping up the gas and employing it. But I think that’s when the quality really came in, we realised we can’t survive doing it the traditional way and stacking six times. So we have been moving in a direction to be more collaborative with our partners. Sharing more, earlier involving then earlier and more deeply in our design so that collectively we can achieve something better than the old dynamic producer.”

“We have global relationships with suppliers of the {product model deleted} and these are different. These are actually risk-sharing partners. We ask them to take on the design, the certification and the fully integrated work for key elements of that aeroplane. With the focus on our sharing partners we are talking with them on a very active basis. It is with any of the products we are working on now. Our expectations are world class. People die when we get things wrong.”

“It is not only the {aviation authority names deleted} regulating that we have to watch that the rivet being installed. Sure we could do that with sophisticated visualisation techniques that in some way might be even better than the human eye. It still requires that a person watches that process and watches every rivet. We have processes and detail fabrication we believe is critical to aircraft integrity. So we certify many people in the process that fabricate parts. And certification processes, laborious, is comprehensive and supplier pays. So, we started to go to ISO standards. There is another international standard we started to use for quality of the actual production. In a preferred supplier chain we look at three things; on time delivery (and we penalize for early deliveries like we do for late deliveries), hitting their cost targets, and quality. We have moved back from inspecting quality in 1983 to building in quality in 2006. Most of our operators are qualified versus inspections.”

“Another process that changed in the last 30 years is we turned to preferred suppliers. We started grading our suppliers. Too many were qualifying to be gold suppliers or silver suppliers. In order to be a gold supplier 10 years ago it was 90%, now it is 99%. We found that suppliers can use that to market their company. When we went to the preferred supplier process, our suppliers’ competitive advantage, we say any new work will first be offered to a gold supplier. And he has first right of refusal. We now only have to work with 7% of our potential suppliers. We foster some of those relationships:

companies that have good potential of moving up the value chain. We will many times work with them. We have a mentor programme where we will target, will work with a particular company to develop the skills necessary to move up the value chain”.
PARTNERSHIP: Information Sharing
“I would say that we meddled in the suppliers business continuously, over all, in everything they do, changes, versus {competitor deleted} giving requirements saying this is what I need when I need it. Thank you very much. And so there are some disruption of the supplier and how we manage. {Competitor deleted} have a longer view. They would commit to buying and time frames different than us. Where they run their production, they were always slow in committing and we were cycling like this. So the supplier had more confidence in that choosing from contract for this much that doing this for a time. I might do a little bit more. So opposed to the supplier with Boeing thinking; ‘well here is the downside, the contract is more than the upside is’. We tend not to share information across. We should be better about sharing information.”
PARTNERSHIP: Risk Management
“We try and manage our supply chain to balance operational risks with costs. It is very difficult because again our opportunity is in some cases of number of suppliers we have available to us, we have to do certain things. It is not very easy. If we’re trying to get avionics we are trying to get 2 or 3 suppliers. You know, if you want to get certain materials, you are talking to 2 or 3 suppliers. Some cases we have more commodity type stuff. Even then it is not as commodity as you think it is. So we’d like to say we have double sourcing on everything. It is not cost effective to do that. We have contingencies, but contingencies are fairly expensive. But we have to do it. And then we don’t have to do it. We do have single point players in our system. And to manage those accordingly, but our business is too stamped with risk.” “But I think going forward if we have a shared destiny then when we talk about lean we don’t want our suppliers to fail. We don’t want them to be so, so lean to the point that they can’t support the whole value chain. So we have to have a really good balance, a mutual interest.” “What does partnership mean to us? It is risk sharing, bringing other partners on board to help influence the decision makers so that we can increase our sales. So it also mitigates our risk investing {amount deleted} on our own. They have been partners, real partners from the beginning of the programme, so they really understood the responsibility and the technology associated with it, the investment they would have to do into technology. We have all the confidence in the world in our suppliers. We do not monitor their progress.” “Quite honestly we have to be global. We have to have those relationships. ...those supplier relationships are really important. If we want to be a large system integrator then we have to trust other people. And the only way we can trust other people is relationships. It can not just be a business relationship it has to be a risk sharing relationship.... We don’t want to blame a supplier to day. We want to work with him to fix it. If there is not the capability then let us move on and find the right supplier.”

"We help (suppliers) in 1000 different ways. Most stop, and we get in trouble not so much on down track as we do on the beginning on an upturn because they don't have enough cash to position on materials, for people, for capital equipment and so forth. And that's where we struggle the most, at the beginning of an upturn."
INNOVATION: Manufacturing Processes
"For the {jetliner model deleted} one roll-out of the factory every 11 days. The goal for the {other jetliner model deleted}, is 3 days. For the {other jetliner model deleted} we have gone from a static line to a full moving line lean production. The relationship with suppliers has become increasingly important to maintain the present type of operation." "However, I would say going from a new programme to a sustaining programme even when you are at the sustaining programme your relationship with the suppliers has changed over the years drastically. Before it was; 'Here is your contract. It is very individual, so this part is within this timeframe which is very short. If I change it you just keep changing inside'. Today it is much more of an open communication, working together, and continuous improvement. It is usually a two year look ahead. 'I am not going to do it individual purchase order, I am going try to do it on a either pull or push system. So it has evolved a relationship, even on a sustaining programme drastically over the years."
INNOVATION: Research and Development (R&D)
"The supply chain functions very differently in a new start of a programme. And we are bringing the {jetliner name deleted} as a new programme, a more sustaining programme. So that, you almost have a different requirement of a supplier's up front capabilities, but within those capabilities now quickly move into a sustaining load. They are a very different set of capabilities. For our supply base, technology is much more related to new airplane models. It is much easier for us to take new technology, get in on a new airplane model than to retrofit new technologies back on to an existing model. So one of the things that we end up doing is that our suppliers get frustrated because there is such, they have to get on a new airplane. So we leverage that, to find a new airplane programme. Once we get on that programme it is difficult to take advantages of technology. So for instance when a supplier comes up with a new idea and technology, getting in on the existing programme is very difficult for us, both in terms of business case and existing incorporation. So I think our technology with our suppliers, we are learning that we have to get better coordinated on, where they are spending R&D money. We are talking to suppliers and they are spending R&D money on something we can't use, until the next airplane, which might be far, 10 years away. And we can really use, spend their technology, R&D money on changing the process with which to produce the existing product at a much lower cost. So it is a balance, it's about getting blurred technology we hadn't really thought about unless a new airplane programme, what technology does the supplier bring. We are starting to have a better understanding of technology capability."
INNOVATION: Network Performance
"What we are learning, we have technology being worked with our {Technology Development business unit}. They are thinking about it from a technology stand point.

Not thinking about it from the supply chain stand point. So how do you get an integrated technology plan that's out there into your supply chain? That's leading your current set of businesses, and it most likely will be the supply chain that leads you into the future. But that's an area that we're really learning quite rapidly on. But it's, I think if evolution, some evolution stand point supply chain, I think it a huge ground for us to have some opportunity and yet some value added." "It is interesting that the collaboration is part of that survival of the fittest, because you have that learning from experience. You go and try something and it evolves if it works well, (when) we pursue other areas that don't, we back off. Keep trying to find the right sequence or pattern of suppliers."
INNOVATION: Risk Management
"We are continuously being surprised by how our products are becoming more high-tech for us and our suppliers. There have been cases where we have developed new technologies that we cannot transfer to our suppliers. There are too many intellectual properties and not enough products. I think you are going to see {name deleted} push innovation and {name deleted} is going to push it through the product level. I think that that is going to give us the next great opportunity." "Our composite development is risky to us. Internally in the {Prime name deleted} we feel we have a lot of composite experience and a lot of it is proprietary to us. We do watch closely how these things are developing. If we start to see a slippage in what is positive forward motion then what we want to do is nurture that technology." "The industry is concerned because of the innovation. We are an extremely risk aversive company and I think this is an indication we have started to accept risk and be innovative. By risk I mean within the production environment. These large scale production systems that we have utilized on a small scale in the past."
INNOVATION: Product Services
"With the {jetliner model deleted} we talked about the life-cycle product teams, not just and once it's out the door it's someone else's problem. We more at the lifecycle of the product than just the product we put out the door. It is this focus saying much more of the business will start at the time of delivery. We always though tended to see services attached to something as an obligation opposed to an opportunity. And so as {Prime deleted} supply chain means less and less actual manufacturing, assembly and then the big group is on the service side. That's what we aspire to. And we just are starting to realize, years and years of talking about how much potential there is and we start to realize that potential."
ENABLER: Information Communication Technologies
"We have developed portals in our system of design and engineering that enables us to work with our suppliers and researchers and partners at a completely virtual basis. And that will enable data transfer, high-level digital, high speed integrated system. That enables us virtually to work in a fairly complex environment of 3D cad etc. These computing tools are incredibly powerful. Enables us to describe what we are doing in some very clear and discrete ways not possible 10 years ago. This has significantly

changed our relationships with our suppliers."
ENABLER: Standards
"The long term health of the business is dependent upon uniform plug in places of design that is integrated into virtually every element. Consequently commercial off the shelf equipment is one of the ways to reduce the cost in the industry as a whole. So generally we would prefer our suppliers to have other customers to help spread the long term involvement of business risk in more than one direction. And I think the risk we look at is more based on repetitive advantage rather than competitive advantage." "Our customers continue to want a customised product. So we're working hard to figure out how you use more and more standard features but be able to quickly, and that maybe agilely, to mix and match to get a customised product to the customer. Because when they are spending all that money they want the airplane to be different."
CONSTRAINT: Government Restrictions
"We had no {home country deleted} export licences required to export overseas. The {home country deleted} worried that we were selling {Far Eastern countries deleted} to any places that might have been considered politically offensive at that time. For the {jetliner name deleted} we had to apply for over 4000 licences. Who in the world is buying our aircraft? And what leverage can they bring to help us maintain market share. So not only is it a decision for production but for marketing and sales and earning some revenue. Significantly different than when we were in a market that was predominantly {home country deleted} airlines."
CONSTRAINT: Industrial Development
"(W)e do that as part of shaping the market, developing the market in a country. But right now we are working, with lots of countries around the world to help develop their airspace industry. It creates good will. Part of our participation in {nation deleted} was to help them legislate, open up the sky, so that you can connect more directly and that favours our product portfolio which pulls through more sales. It's a really long term perspective. {Prime deleted} knew {foreign nation} would be buying airplanes and they would have substantial growth in the business in the future. So they started to work closely with the industry, e.g. software engineers and to develop engineering skills because we know that when we introduce commercial aircraft into a commercial market those airlines would need engineers help them maintain those airplanes. In {another foreign nation} they recognise or they appreciate formal relationships. When they talk about relationships they talk about generations. I have known your family. My grandfather knows your family. They have done business for hundreds of years. Now they respect you. The approach is much different than if you walk in {foreign nation}. The king of the country is a decision maker but he obviously makes very few decisions. He depends upon a cast of advisors who come to him with information. You have to look at who is the decision maker. If you influence him (it) does not matter. Who influences him? Work with them instead.

So, when we look at the third world that has no infrastructure, roads and they are expressing an interest in acquiring an airline then you can create a win-win situation. How are people going to get to the airport and utilize the service if there is no infrastructure?”

APPENDIX M – TRANSCRIPTS – OEM(B)

Extracts from transcripts of interviews held at OEM(B) are presented in this appendix, organized by core category (shown in capital letters in headings) and sub-category. Unbroken quotes indicate one interviewee's words. A series of dots (…) indicates that superfluous text has been removed, which does not add (nor detract) from the points being made. Brackets show text added by the author to aid the reader and are not intended to divert from the words spoken by the interviewee.

PRIME DOMINANCE: Risk-sharing
"And if you look at the main contracts … it is a partnership you know. They have become really a part of our business in the way their contract reflects. There is risk associated with that obviously. That is how we are handling our major contracts. So if you look at the {programme name deleted} programme it is very specific about what you must do to a supply product, how you should run your business and what you should do. With your suppliers as well and there is a flow down of requirements." "Both {primes deleted} have methodologies for trying to understand their supply base and trying to minimize risk The templates that {the primes deleted} use are different. The {prime name deleted} ones fall in modules are a little bit more prescriptive. The {other prime deleted} one, we tend to see more of the people. They will listen to your assessment of the supply chain risk as opposed to {other prime deleted} they will send you a format." "And that is the time when the suppliers remain the IPR. You buy something where you don't know how to inherently make it. Where IPRs as suppliers would make a contract that means in the airframe where something goes totally wrong we will remain the foreground IPR to answer that specific area."
PRIME DOMINANCE: Supply Chain Effects
"From a supplier perspective we are really formalising the partnerships we have with larger suppliers. And the more tactical relationships we have for machined items. Having the effect of polarising the supply base into partners where, technology partners effective with a common interest in an aircraft platform. And commodity providers where, there is always a barrier to entry, barriers to access. Whereas previously the line was more blurred on that it is becoming clearer, divisions are becoming clearer and that defines what levels we do in terms of outsourcing. Now that is really maturity, maturing responses of the needs of use are actually doing. It is not something, I think, that is dictated by {the primes in here} although they understand the core part of the system they want to see a different relationship." "How we tend to work now is a much more collaborative approach. We join. We have cross-functional development teams here where we have manufacturing development engineers, purchasing etc all in the same team. And quite often, quite frequently we will have a supplier sitting for the couple of weeks that it takes to trash out the details of their policies."

"Both {prime deleted} and {another prime deleted} are interested in our reducing of supply chain members, who our main partners are and what their readiness plan is. They have got different templates on how they want to see their readiness data which is inconvenient. There are different phases that {prime deleted} was earlier to the systems party and there I think that process is more mature in terms of how they ask questions on the subject. But more the same trajectory within three years of each other. We won't talk about our customers."
PRIME DOMINANCE: Future is Services
"We are going to have to change what we are offering to the customer to be able to make business sense. We make very little money on how we manufacture. Where you make the money is in the after market. But the after market itself is trending towards power by the hour. I want to buy a flight hour in the {airframe model deleted}. What that is the price you can give me for the flight hour? My business in {airline deleted} is to move people from there to there as quick as possible with a level of service. I pay you 50 dollars per flight hour. You can take care of everything else. And that is where we are trending." "To make money out of that we have to get much smarter at providing service. Clearly have to take money out of our OE product. Even if you accept you are going to make more and more money on the OE product they want to maximise it. And then we will have to think very carefully about how do we move? Because the longevity of the product is extending, the customers are staying longer on the aircraft. How are we going to make money out of that? We couldn't lose money on our way and then wait another 5 years after the aircraft has been into service before we start getting revenue for it. We need to do something immediately. So, that is where the trend is going."
REVOLUTION: Systematization
"Our role in the supply chain is changed. We are taking on work on {specific systems deleted} … (which are) 3 major systems we have on {airframe model deleted}. We are taking on more, we are taking on the role of a tier 1 system integrator. So as opposed to previously the {another airframe model deleted} we would have supplied subsystems or components to another company that might have co-operated them or directly to {prime deleted} who might have pulled everything together. On the {name deleted} system for example we are now doing work that previously {prime deleted} would have done on {airframe deleted}. Our responsibility is to integrate that and give it to {prime deleted}. And it is that integration {prime deleted} would previously have done themselves. Similarly on {a third airframe model} for {another prime deleted} we have stepped up a notch in the food chain to be tier 1 system integrator. Very, very important because that is the fundamental part of our strategy. To get up to that position where we still interface directly with the prime, that is in the long term the only way to sustain in a competitive position within the aerospace supply chain. Because what will happen is when you go further down things will become more and more commoditised. And it is more and more on price. At least at the system integration level you can differentiate yourself on, in terms of the engineering expertise and your system integration expertise. But it is difficult to get that. "So the {another 1st tier firm deleted} approach have been to gather the view of best

practice, document the role of supply chain. The {prime deleted} approach and that has become the {another prime deleted} approach has not been so much about that total philosophy. If you look at the {jetliner model deleted} designed in the 60s, all the {system deleted} systems were designed by {prime deleted} designers and then made to print contracts. So anyone working to {prime deleted} contracts worked to their design and their standards. The next step along was for {prime deleted} contracting to individual units of that to suppliers like {1^{st} tier firm deleted}. And the next was subcontracting the whole system. That means a total difference in supply chain needs. It has been to break the aircraft up into systems and to use fewer larger suppliers to supply a system. And to delegate the responsibility of supply chain management of the system to companies like us. And so we have positioned ourselves as a system supplier. Whereas I guess some time ago they saw themselves as replacement unit suppliers. And indeed that in itself was an evolution”
REVOLUTION: Firm Growth
“So we are looking at a growth curve that will double its size and in 3 years. So this whole business is structured towards change and growth. But the whole business is absolutely structured towards change. If you walk the shop-floor here about 50% has been relayed in the last 2 years. And it is a big shop-floor. So culturally we are very used to change. Learning and development is pretty much embodied.”
REVOLUTION: 2^{nd} Tier Challenges
First of all as we move up the suppliers have to move up behind us. They have to then take on, because we don’t want to become very vertically integrated. That is not the strategy. We want to concentrate on the real value added portion of this which is the system integration. So, I think there will be a very broad trend towards us buying more and making less. At the moment what we are doing is sourcing component levels activity into the supply base. Things that we were making in-house we are gradually moving outside. But rather than putting them into the {countries deleted} supply base, we are trying if possible to put them into low-cost economies. What that means for the {country deleted} domestic supply base they have to either get lower cost, which is going to be difficult or they got to compete some other way. And I think the way they have to compete is rather than trying to position themselves to win volume running OE products which makes in broad terms more sense to make in {low cost economy country deleted} because of lower cost. They are going to have to position themselves at the low volume, high variety, high complexity end of the road. That sort of work is very difficult to move into a low cost economy at the moment. And probably will be for at least the next 3 to 5 years. So we give them component design and manufacturing. Buy the whole thing from them. And that is going to require them to develop their capability. As they {prime} are passing on work to us, unless we want to become more vertically integrated, which we don’t, then we have to pass it off to somebody else. And of course that puts a big pressure on your suppliers, your supply chain management process, supplier identification, supplier selection, development and performance management. as we move civil production work out to LCEs we will still need to have access to suppliers who can develop, who can do the initial development work on an aircraft programmes. So again it is all about expertise, fast response, low volume, engineering content. So, we can go to them and say look; we have, we need 20 of these to support the qualification programme for this aircraft and initial hardware. Here is an

outline spec. You go away, detail design it, manufacture it. And
maybe 2 years thereafter that programme is going offshore. So, mister supplier you won't have the volume production. Some of them won't be able to deal with that. But that is the reality of life. What we call lean, agile, fast response type of suppliers."

"So if you look at all the engineering tasks required to delivering a new product we examine those and classify them as either core or non-core. All of the core ones we retain in-house. Those are mainly concept design, architectural design, qualification and systems integration. And pretty much everything else we can buy outside. And detailing, solid modelling and MC programming, technical specification, stress analysis, reliability and maintain ability analysis, some manufacturing engineering work; all of those things we are working with a company in {Far East country} to deliver. We don't need to engineer that anymore, it is not core. Now, we are retaining some of this. But for the commercial aerospace we are looking at, to get as much as possible out into low cost economies, because it helps to reduce the non recurring engineering costs. It makes the programme look more healthy."

"One of our prerequisites of supplier selection You know I say 3 times a day we will not select the suppliers unless they prove it is demonstrated in change mindsets. So they maybe great today. They may have a great product today. They may have great prospects today. That is not enough If they are great but standing still 3 years in time the will not be great anymore. That is in the same list as having a robust quality system."

"So, whereas I think 3 or 4 years ago through the SBAC using district forums for developing supply chain relationships. And that was based on the assumption that UK suppliers could compete on a global level. They cannot compete on cost. I think there is a growing realisation that that is the case. "

"Traditionally innovation with the suppliers has not been that great. We have done most of it and it is passed down a detailed spec or a drawing in a sense. Make one of those or maybe a dozen of those! As we step up we really need to find suppliers who can grow and develop and contribute to that innovation process. s we move up the food chain then we push some of that into the supply base. It is one thing to source it into the supply base and the cost for it now. But because of the pressure of the market we will need a supplier to continuously develop an innovative, new method of making that part. That is where we are spending, where our internal teams are spending their time now."

"To develop an aircraft, to jointly develop an aircraft that is designed for manufacture. That is the key thing. That is what I am trying to say here. Design to manufacture. Design for cost is more important aspect in the current environment than it has been in the past."

"Within mechanical systems we have got somewhere in the region of 300 suppliers of mechanical components. It is far too many. We have not got any, much, no.' if you take the exception of about 10 of those suppliers that has got some fairly sizeable turnover with us, the rest of them are very, very diverse. So we have got very little financial relationship with them. They are mostly small, at the bottom end size wise. They have not got the means to attract good engineers. 'A' because they can't pay them and 'B'

because a good engineer would not go and work in a 10 or 15 man company. And they have not got the investment to be able to join the {university innovation and development unit}.”
GLOBALIZATION: Competitive Advantage
“We are talking about the commercial sector specifically. Quality is a given. You don’t get anything into the air unless it goes through certification and qualification. So that is a given. Delivery times response time and new product introduction time is becoming a very, very important factor. Because the customers, the airframes, are reducing the time taken to put new products into service so, we need to reduce our new product introduction time. So clearly those time pressures are becoming bigger, but far away the biggest driver on this is cost.” “(W)e are already losing money on {airframe model deleted} and we are facing the development of a product where price is halved. And then what we are seeing for {a second airframe model deleted} which is the future aircraft programme is an indication that it will be about 30% lower than {a third airframe model deleted}. That is getting to the point where you are almost down, if you are not already at the `price of raw materials before you have even done any processing. So what it is saying is that it isn’t sustainable. And you have got to do something different. You have got to offer a different business model. So the customer you have got has to use some different architecture of your system. You got to get very innovative with your solution. We have had to go out and do much more low cost economy sourcing. And if from a supply chain point of view, if I was to look at the one key driver that has come out of cost it is LCE.” “So the key pressures are really costs. But the current {airframe model deleted} is around {price deleted} list price. We have heard {airframe prime} say unless they can make the list price of the aircraft {price deleted – but under half price}, then it is not worth bringing to market. So you can see where the price pressure is coming from. {Prime deleted} is sending a shockwave through the industry with the {airframe model deleted} pricing.” “That is an agreement we have with {prime deleted}. We have a very stringent price target. It is flat for 5 years and then it starts decelerating 2 ½ % year on year. It is `tackled by pushing as much as we can at the moment into low cost economies. When we get into volume production it will ultimately be 0 %, not even final assembly and it will be really the engineering, and support functions, marketing and so on that will be left in the {Western country deleted}.”
GLOBALIZATION: Classifying LCEs
That brings a whole raft of challenges in terms of how we develop those suppliers offshore. We are actually building a, we have a procurement team in {Far east country deleted}. We are expanding that team now. They will be local people and at least for the next 2 years they will be lead by an expat manager. We have divided {Far east country deleted} into 3 regions. And we are developing a team in each of these regions of local people. After 2 years, I think, the likelihood is that there our {Western country deleted}

executive will come back and he will possibly be replaced by a {Far eastern} person. But even in that 2 year period we have got {Far eastern} locals because they are in a much better position to interface regularly with the suppliers in the region. And what we want to do is, although exclusively at the moment those suppliers, we are interfacing with those suppliers on a make to print basis. Giving them a drawing and saying; can you make one of those? Again we need to think about where we need to go to in the next aircraft programme. What we are looking at is sourcing entire alloy use and replacement units with them. So they are not just doing a year or casing, they are doing all of the years and casings. They are buying the parts from the people we are buying the parts from.

GLOBALIZATION: In-country Builds

We fully expect that when it comes to the next generation of narrow-body aircraft, that {major primes deleted} will mandate a level on in-country content as part of the contract. So, rather than saying to us; look here is the target price, this is what the system needs to do. They will almost certainly say; oh, by the way we want you to put 20 % of your production into {Far East country deleted}. The reason why they want to do that of course is for those aircraft particularly, those narrow-bodied aircraft, huge proportion of the sales will come from {Far East country deleted}.. And {Far East country deleted} itself will not simply only want to buy aircraft they would like to minimise. Are you aware of that {prime deleted} has just announced their intention of setting up an {airframe model deleted} final assembly plant in {location in Far Eastern country}. Yes. If you look at that build line in {location in Far Eastern country} will according to the press release be for only those {airframe model deleted} that are sold within {Far East country deleted}. And there is a significant number of those. But it would not take a good leap of faith to think when it come to the next generation of {airframe model deleted} they would simply say lets quit all these in {western location deleted}. Let's build them in {Far east country location}.

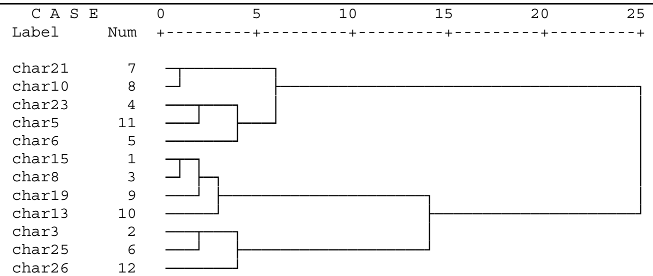
ENABLER: Automation

"I mean there are other elements that, of supply chain manufacture even on the volume side which does not make a lot of sense to put into low cost economies. If you can invest in technology and automate or to an extent automate production then you take the labour out and there is not of benefit to go offshore. If you can do that one man running maybe 3 or v4 or half a dozen machines the cost of that man relatively to the total cost is relatively small. So if you literally picked that up and put it into {Far East country deleted} you have saved almost nothing. Because, the most you have almost saved is 9/10 of a man. On an entire system that may have cost you 1 million to put in place. So I think there will be, there are exceptions. Not everything will naturally migrate offshore. The only counterargument to that is that it is very, very difficult within aerospace to automate final assembly.   On our relatively low volumes you cannot get the justification with the very high complexity. So what is left is high touch time content. So that what makes most sense to put into {Far East country deleted} because it is all labour. So if you have got your final assembly in {Far East country deleted} in some instances it says it makes a lot of sense having these supply parts in {Far East country deleted}. Even if in the example I gave earlier you are not making an awful lot of saving, it makes more sense logistically to have your manifold supply cell next to your final assembly.

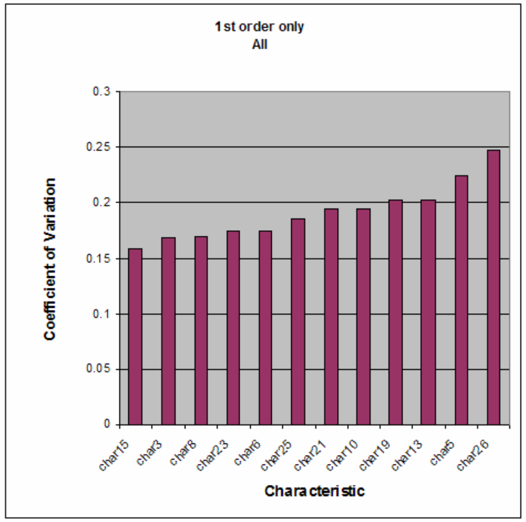
CONSTRAINT: Quality
"And that has been one of the barriers getting the quality systems in place and getting the relevant approaches in place to carry out that processing in the low cost economy countries. That is something that you can't leave the {Far Eastern country} suppliers to do themselves. It has to have our influence on western standards." "(T)he interesting thing that is the key locking LCE potential.. 15 to 20 % of the parts require maybe very, very limited processes or maybe require a right at the end of the production cycle. The other 80 % require processing frequently throughout the manufacturing cycle. And you can't afford flying parts backwards and forth. So you have to unlock the machining capability which is clearly evident within {Far East country deleted}. You have to unlock the special processing ability. So we have been putting a lot of effort into doing that. But it has to be with its own people. And the competitors are doing it as well. But it does make, the quality insurance side of it is much more complex." "De-focusing to smaller LCE is not yet a priority. Immaturity of supply base is a problem for the second priority. The nation's indigenous aerospace company are very vertically integrated. They have come to the realisation that they can do everything. So, they are now starting to outsource more. But it is a very early stage. The biggest most capable suppliers are really at the very lower end of the component supply." "The other thing as we move up to tier 1 is not just about manufacturing technology it is also about engineering technology. So the more we can give particularly to LCE suppliers, the bigger the size of packages we can give to them, the more chance we have to making savings and making the business case work. People think about {Far East country deleted} in terms of part manufacture. A bigger opportunity is really about giving them entire design, make packages and say ok you are going to take this part, this entire part of this system, or this little gear down here or little prismatic part of this bunch of machined parts. You are not going to take the whole of that. We will spec it in terms of an outline spec. You take it away, detail it, design it, deliver it, an ongoing production. And so the role we have been doing in-house in terms of design and concept, detail design they will need to take on board. Start them with a fairly simple stuff So we are not building on something that is not there. But we have got to take them through it step by step so they get to grips with western standards."

APPENDIX N – Survey Results

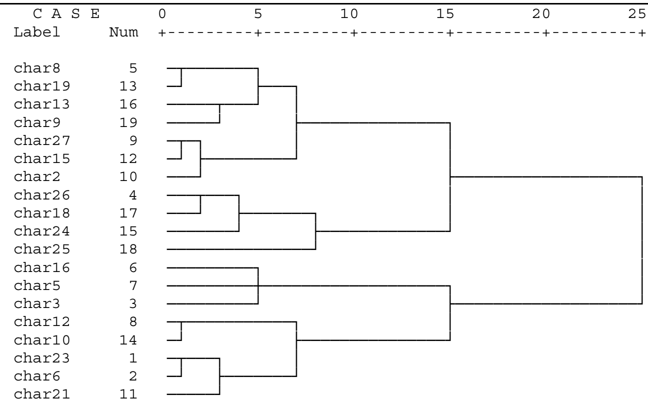
FIRST ORDER ONLY – ALL FIRMS



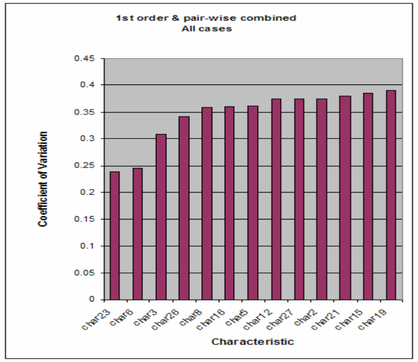
cluster 1		cluster 2	
char21	TQM procedures	**char15**	**high level of planning and control**
char10	sharing knowledge	char8	flexible operations
char23	lean practice	char19	responsive to market change
char5	long term relations	char13	can handle cultural differences
char6	formal partnership	**char3**	**high level collaboration**
		char25	investment in training
		char26	supplier development



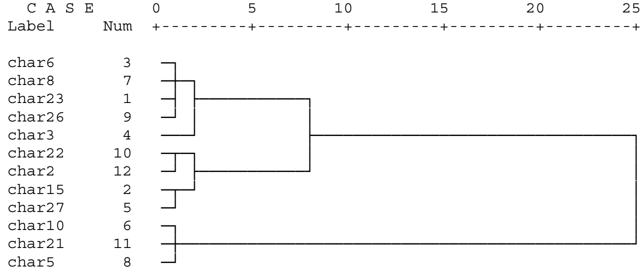
FIRST ORDER AND PAIRWISE – ALL FIRMS



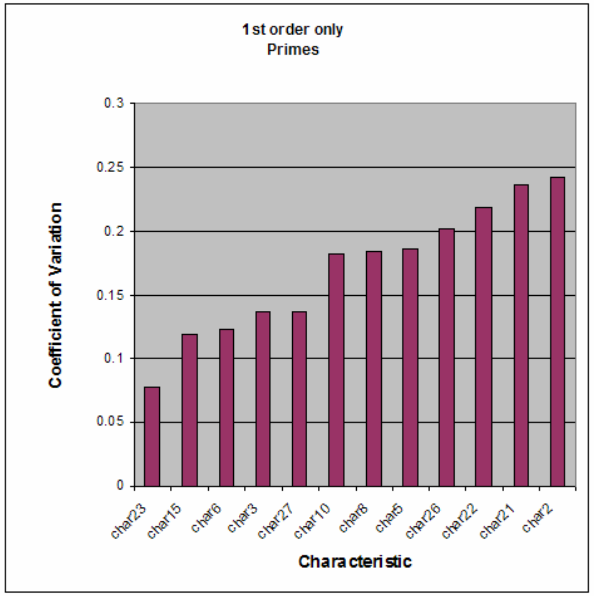
cluster 1		cluster 2	
char8	flexible operations	char16	easy dialogue with supplier
char19	responsive to market change	char5	long term relations
char13	can handle cultural differences	char3	high level collaboration
char9	risk-sharing	char12	culture of continuous improvement
char27	monitoring supplier	char10	sharing knowledge
char15	high level of planning and control	**char23**	**lean practice**
char2	outsource easy imitable	**char6**	**formal partnership**
char26	supplier development	char21	TQM procedures
char18	high levels of integration in chain		
char24	explorative learning practices		
char25	investment in training		



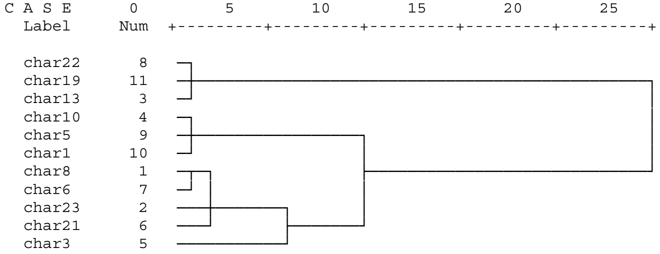
FIRST ORDER ONLY – PRIMES ONLY



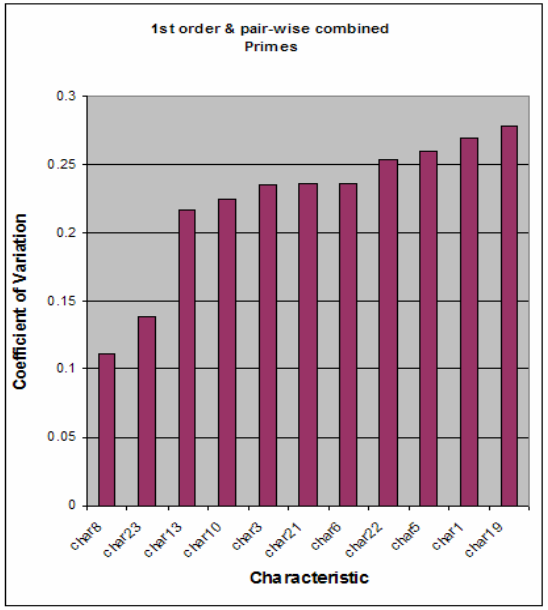
	cluster 1		cluster 2
char6	formal partnership	char10	sharing knowledge
char8	flexible operations	char21	TQM procedures
char23	**lean practice**	char5	long term relations
char26	supplier development		
char3	high level collaboration		
char22	just-in-time delivery		
char2	outsource easy imitable		
char15	**high level of planning and control**		
char27	monitoring supplier		



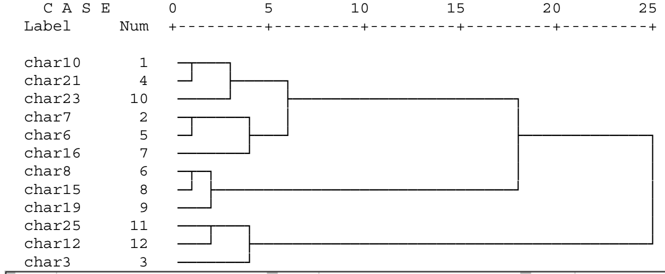
FIRST ORDER AND PAIRWISE – PRIMES ONLY



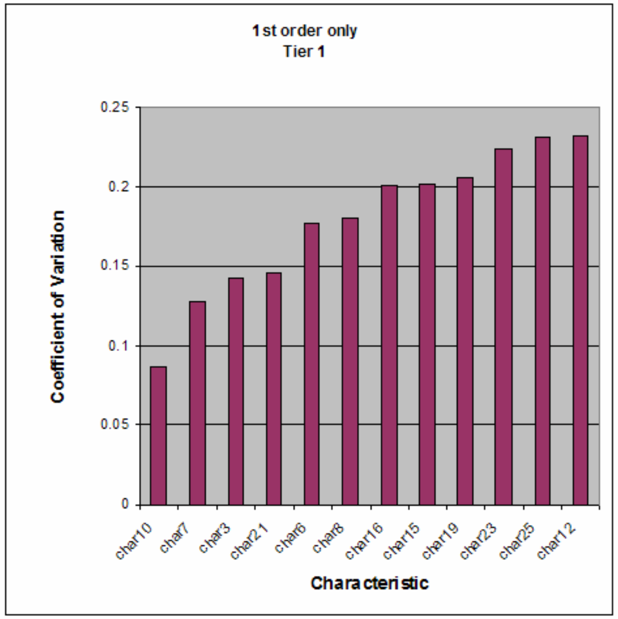
	cluster 1		cluster 2
char22	flexible operations	char10	sharing knowledge
char19	can handle cultural differences	char5	long term relations
char13	responsive to market change	char1	outsource competitive adv
		char8	**flexible operations**
		char6	formal partnership
		char23	**lean practice**
		char21	TQM procedures
		char3	high level collaboration



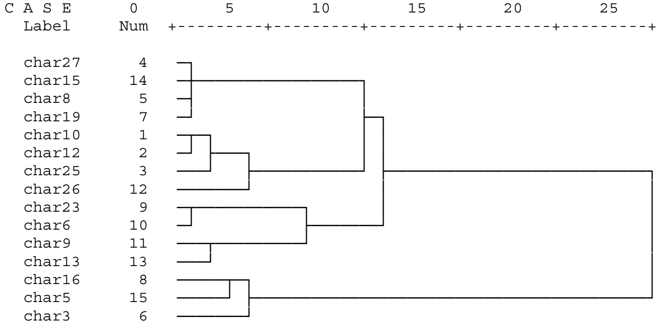
FIRST ORDER ONLY – 1ST TIER ONLY



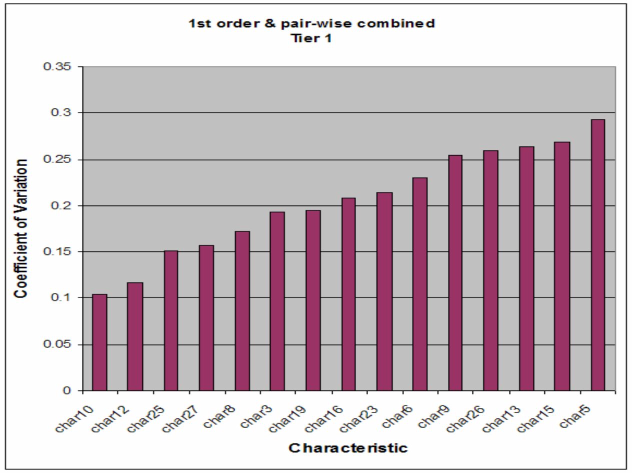
cluster 1		cluster 2		cluster 3	
char10	**sharing knowledge**	char8	flexible operations	char25	investment in training
char21	TQM procedures	char15	high level of planning and control	char12	culture of continuous improvement
char23	lean practice	char19	responsive to market change	char3	high level collaboration
char7	**subcontract whole systems**				
char6	formal partnership				
char16	easy dialogue with supplier				



FIRST ORDER AND PAIRWISE – 1ST TIER ONLY



cluster 1		cluster 2	
char27	monitoring supplier	char16	easy dialogue with supplier
char15	high level of planning and control	char5	long term relations
char8	flexible operations	char3	high level collaboration
char19	responsive to market change		
char10	**sharing knowledge**		
char12	**culture of continuous improvement**		
char25	investment in training		
char26	supplier development		
char23	lean practice		
char6	formal partnership		
char9	risk-sharing		
char13	can handle cultural differences		



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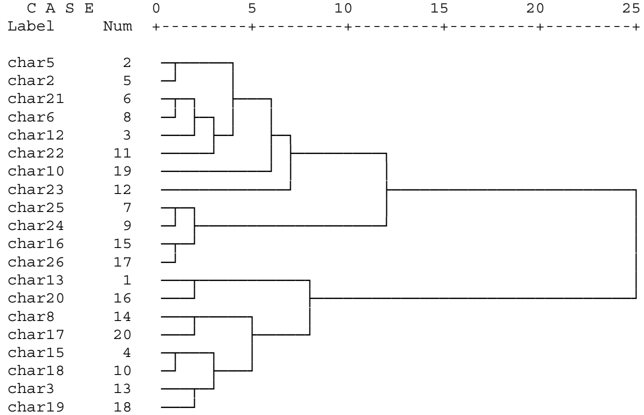
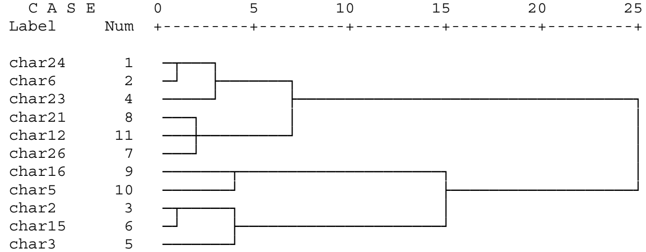
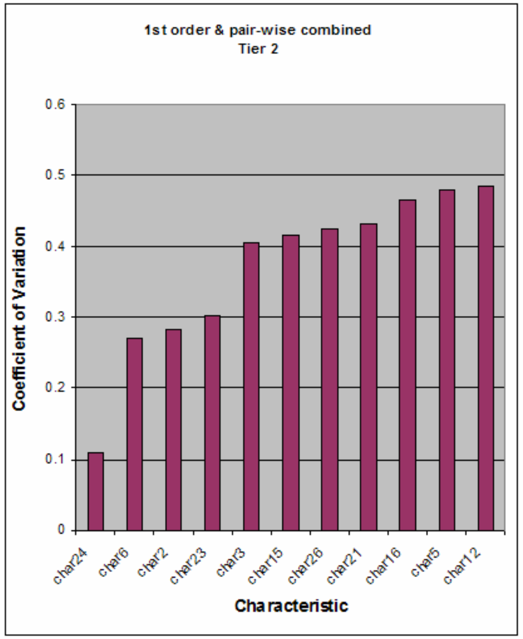


cluster 1		cluster 2	
char5	**long term relations**	**char13**	**can handle cultural differences**
char2	outsource easy imitable	char20	transparent organization
char21	TQM procedures	char8	flexible operations
char6	formal partnership	char17	IT system integration
char12	culture of continuous improvement	char15	high level of planning and control
char22	just-in-time delivery	char18	high levels of integration in chain
char10	sharing knowledge	char3	high level collaboration
char23	lean practice	char19	responsive to market change
char25	investment in training		
char24	explorative learning practices		
char16	easy dialogue with supplier		
char26	supplier development		

FIRST ORDER AND PAIRWISE – 2NDTIER ONLY



cluster 1		cluster 2	
char24	**explorative learning practices**	char16	easy dialogue with supplier
char6	**formal partnership**	char5	long term relations
char23	lean practice	char2	outsource easy imitable
char21	TQM procedures	char15	high level of planning and control
char12	culture of continuous improvement	char3	high level collaboration
char26	supplier development		



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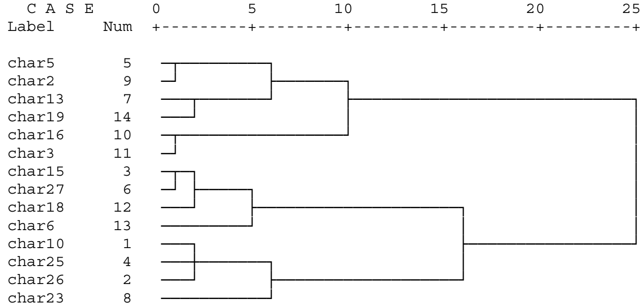
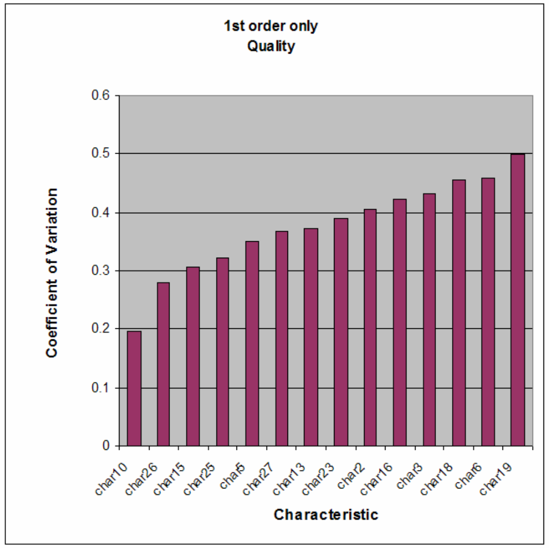
FIRST ORDER ONLY – QUALITY ONLY – ALL FIRMS



	cluster 1		cluster 2
char5	long term relations	char15	high level of planning and control
char2	outsource easy imitable	char27	monitoring supplier
char13	can handle cultural differences	char18	high levels of integration in chain
char19	responsive to market change	char6	formal partnership
char16	easy dialogue with supplier	**char10**	**sharing knowledge**
char3	high level collaboration	char25	investment in training
		char26	**supplier development**
		char23	lean practice



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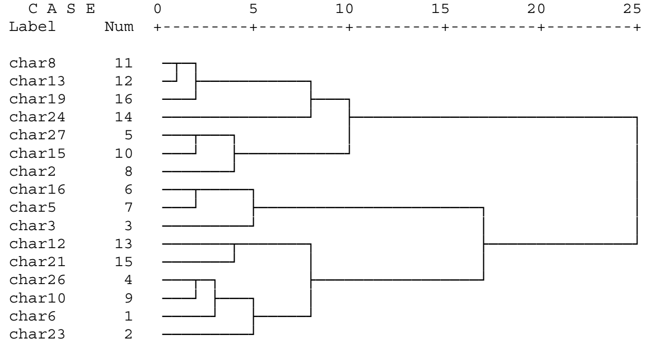
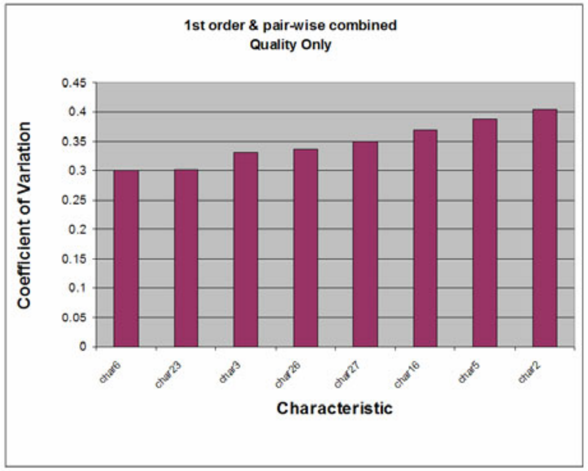


	cluster 1		cluster 2
char8	flexible operations	char16	easy dialogue with supplier
char13	can handle cultural differences	char5	long term relations
char19	responsive to market change	char3	high level collaboration
char24	explorative learning practices	char12	culture of continuous improvement
char27	monitoring supplier	char21	TQM procedures
char15	high level of planning and control	char26	supplier development
char2	outsource easy imitable	char10	sharing knowledge
		char6	**formal partnership**
		char23	**lean practice**



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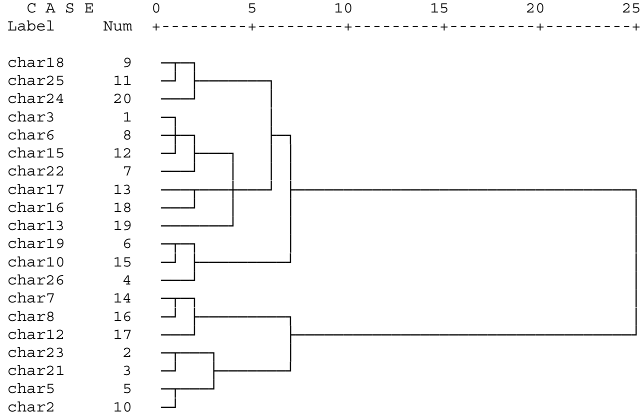
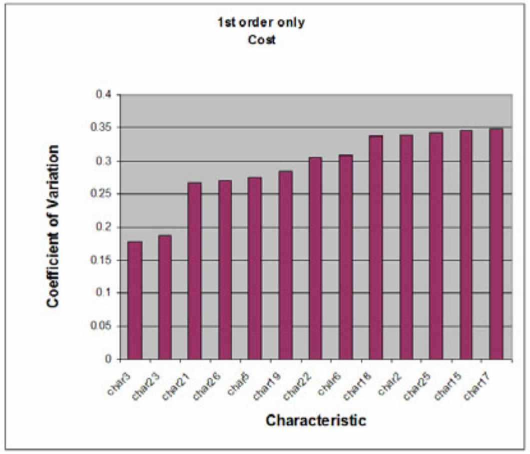
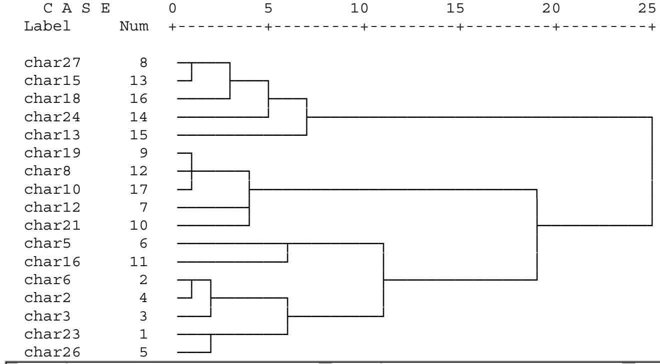


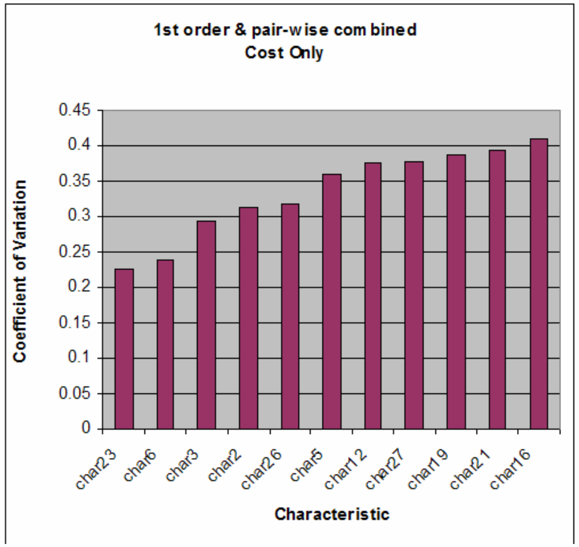
	cluster 1		cluster 2
char18	high levels of integration in chain	char19	responsive to market change
char25	investment in training	char26	supplier development
char3	**high level collaboration**	**char23**	**lean practice**
char6	formal partnership	char21	TQM procedures
char15	high level of planning and control	char5	long term relations
char22	just-in-time delivery	char2	outsource easy imitable
char17	IT system integration		



FIRST ORDER AND PAIRWISE – COST ONLY – ALL FIRMS



	cluster 1		cluster 2		cluster 3
char27	monitoring supplier	char19	responsive to market change	char5	long term relations
char15	high level of planning and control	char8	flexible operations	char16	easy dialogue with supplier
char18	high levels of integration in chain	char10	sharing knowledge	**char6**	**formal partnership**
char24	explorative learning practices	char12	culture of continuous improvement	char2	outsource easy imitable
char13	can handle cultural differences	char21	TQM procedures	char3	high level collaboration
				char23	**lean practice**
				char26	supplier development



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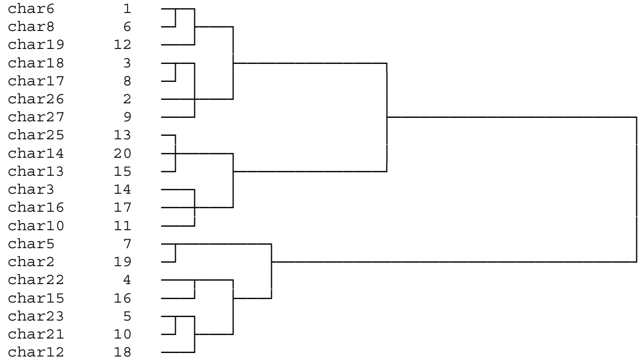
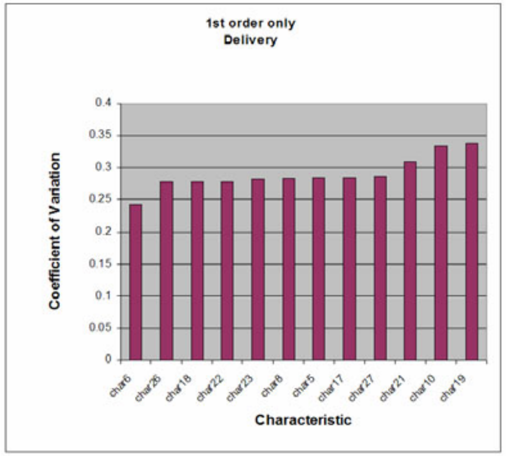


	cluster 1		cluster 2
char6	**formal partnership**	char5	long term relations
char8	flexible operations	char22	just-in-time delivery
char19	responsive to market change	char23	lean practice
char18	high levels of integration in chain	char21	TQM procedures
char17	IT system integration		
char26	**supplier development**		
char27	monitoring supplier		
char10	sharing knowledge		



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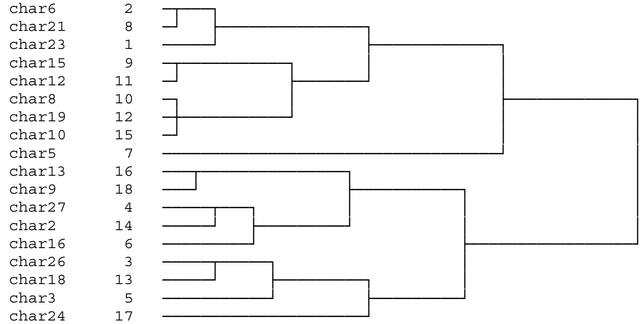
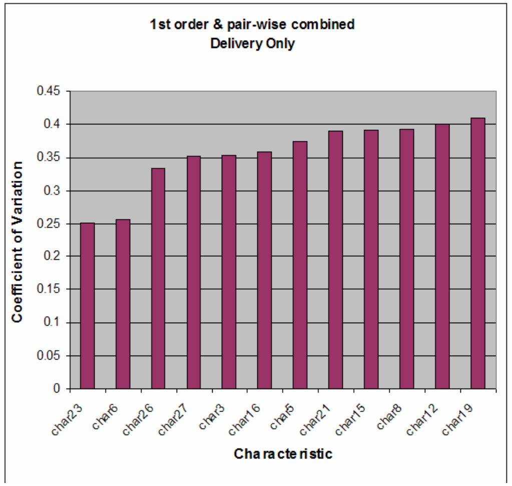


	cluster 1		cluster 2
char6	**formal partnership**	char13	can handle cultural differences
char21	TQM procedures	char19	responsive to market change
char23	**lean practice**	char27	monitoring supplier
char15	high level of planning and control	char2	outsource easy imitable
char12	culture of continuous improvement	char16	easy dialogue with supplier
char8	flexible operations	char26	supplier development
char19	responsive to market change	char18	high levels of integration in chain
char10	sharing knowledge	char3	high level collaboration
char5	long term relations	char24	explorative learning practices



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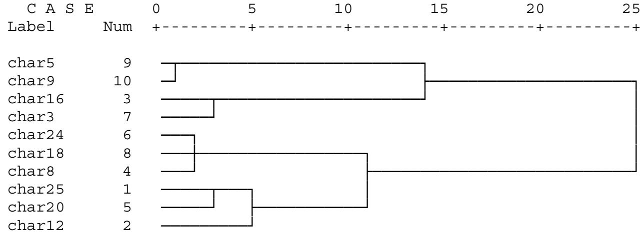
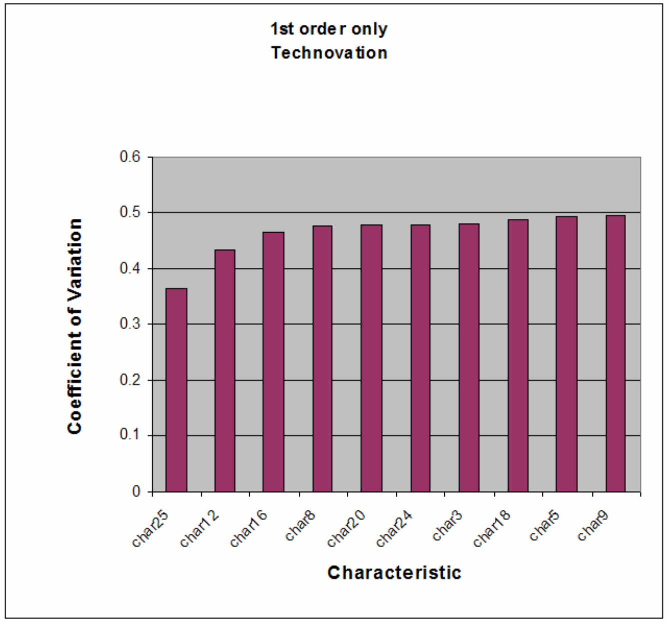


	cluster 1		cluster 2
char5	long term relations	char24	explorative learning practices
char9	risk-sharing	char18	high levels of integration in chain
char16	easy dialogue with supplier	char8	flexible operations
char3	high level collaboration	**char25**	**investment in training**
		char20	transparent organization
		char12	**culture of continuous improvement**



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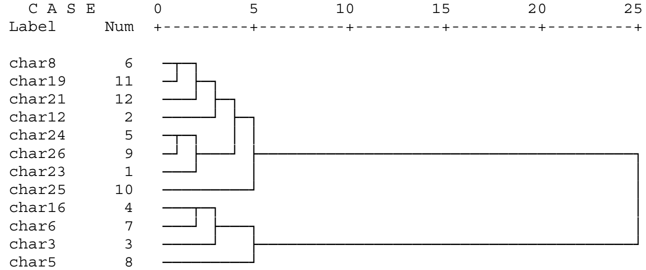
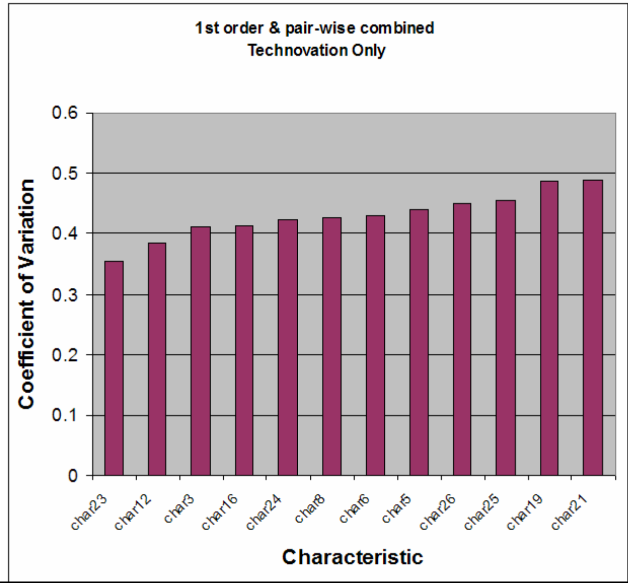
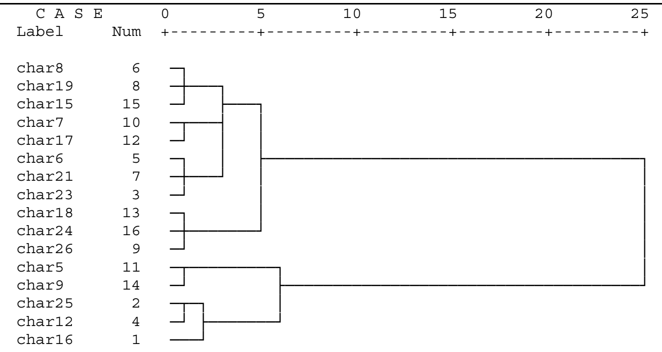


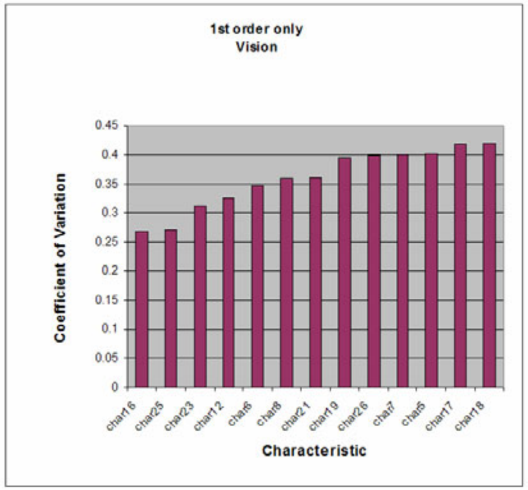
	cluster 1		cluster 2
char8	flexible operations	char16	easy dialogue with supplier
char19	responsive to market change	char6	formal partnership
char21	TQM procedures	char3	high level collaboration
char12	**culture of continuous improvement**	char5	long term relations
char24	explorative learning practices		
char26	supplier development		
char23	**lean practice**		
char25	investment in training		



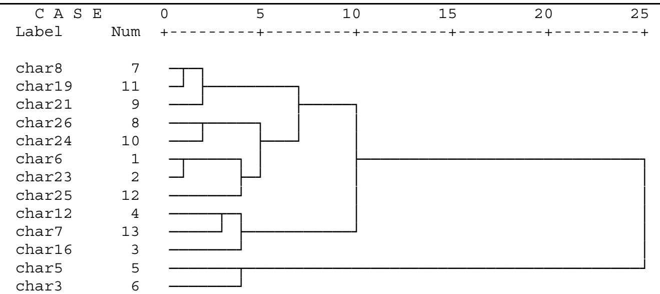
FIRST ORDER ONLY – VISION ONLY – ALL FIRMS



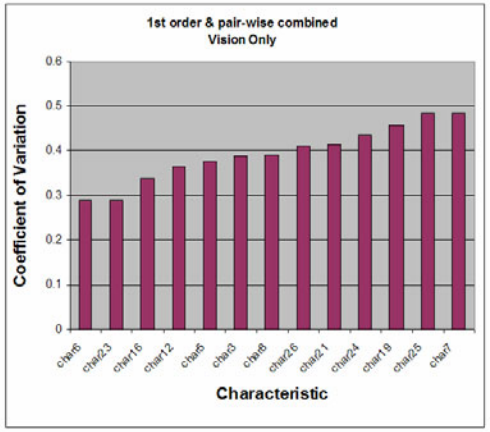
	cluster 1		cluster 2
char8	flexible operations	char5	long term relations
char19	responsive to market change	**char25**	**investment in training**
char7	subcontract whole systems	char12	culture of continuous improvement
char17	IT system integration	**char16**	**easy dialogue with supplier**
char6	formal partnership		
char21	TQM procedures		
char23	lean practice		
char18	high levels of integration in chain		
char26	supplier development		



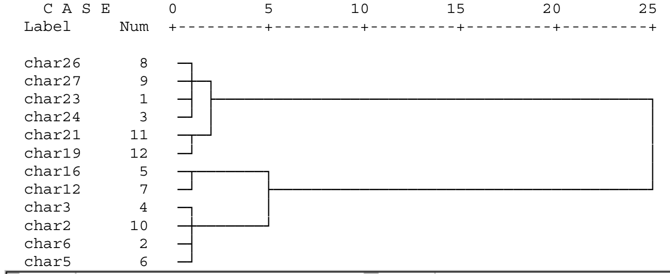
FIRST ORDER AND PAIRWISE –VISION ONLY – ALL FIRMS



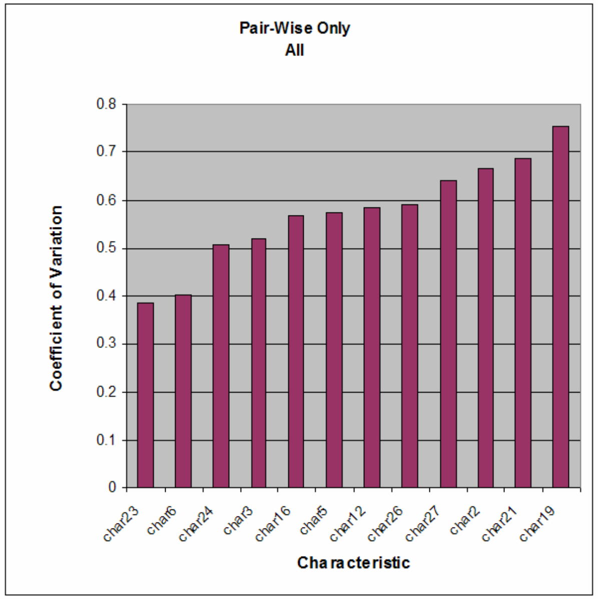
	cluster 1		cluster 2
char8	flexible operations	char5	long term relations
char19	responsive to market change	char3	high level collaboration
char21	TQM procedures		
char26	supplier development		
char24	explorative learning practices		
char6	**formal partnership**		
char23	**lean practice**		
char25	investment in training		
char12	culture of continuous improvement		
char7	subcontract whole systems		
char16	easy dialogue with supplier		



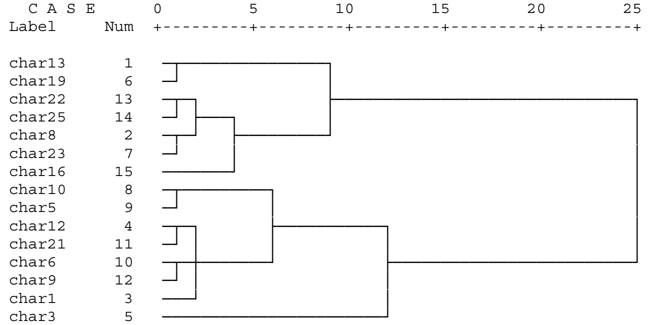
PAIRWISE ONLY – ALL FIRMS



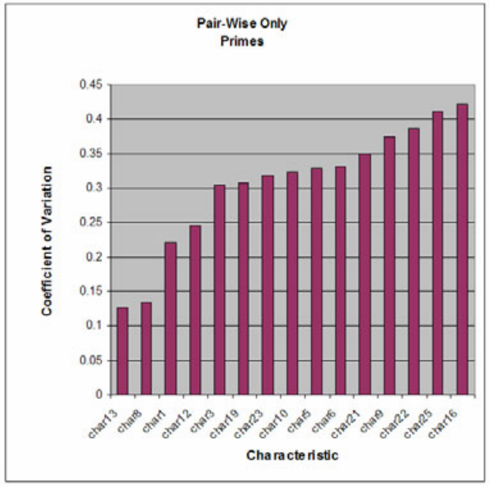
cluster 1		cluster 2	
char26	supplier development	char16	easy dialogue with supplier
char27	monitoring supplier	char12	culture of continuous improvement
char23	lean practice	char3	high level collaboration
char24	explorative learning practices	char2	outsource easy imitable
char21	TQM procedures	char6	formal partnership
char19	responsive to market change	char5	long term relations



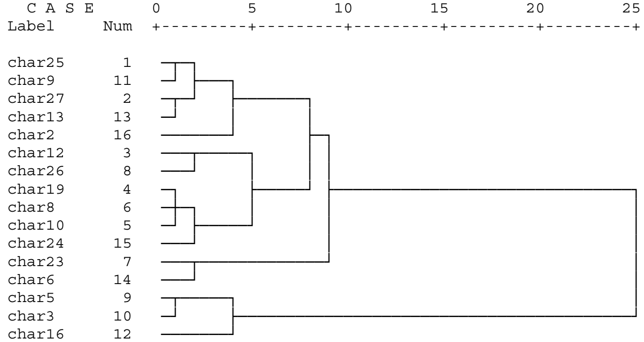
PAIRWISE ONLY – PRIMES ONLY



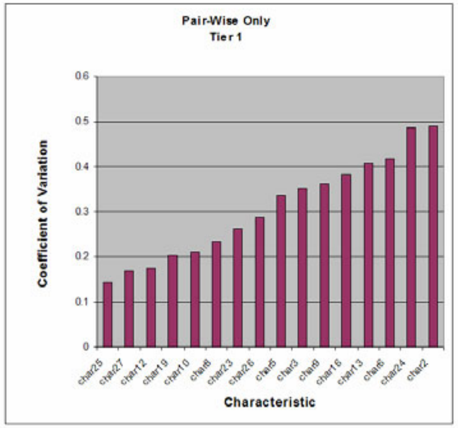
cluster 1		cluster 2	
char13	**can handle cultural differences**	char10	sharing knowledge
char19	responsive to market change	char5	long term relations
char22	just-in-time delivery	char12	culture of continuous improvement
char25	investment in training	char21	TQM procedures
char8	**flexible operations**	char6	formal partnership
char23	lean practice	char9	risk-sharing
char16	easy dialogue with supplier	char1	outsource competitive adv
		char3	high level collaboration



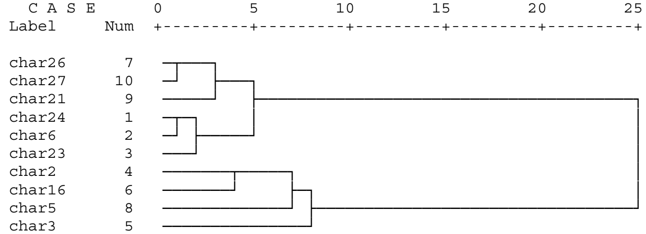
PAIRWISE ONLY – 1ST TIER ONLY



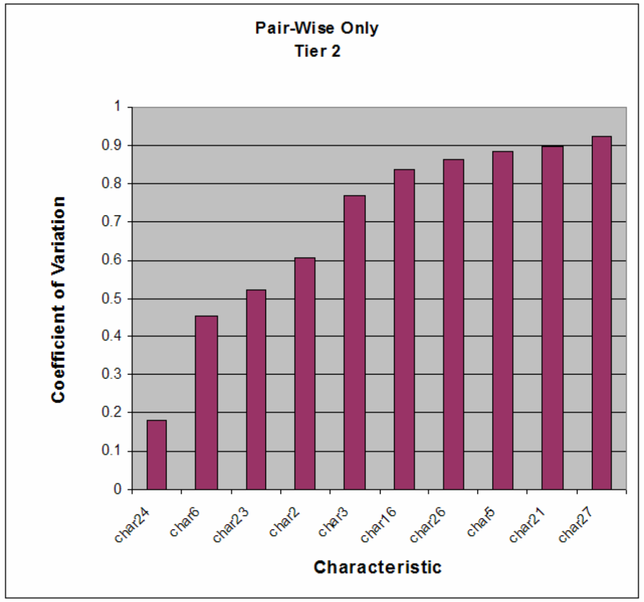
	cluster 1		cluster 2
char25	**investment in training**	char5	long term relations
char9	risk-sharing	char3	high level collaboration
char27	**monitoring supplier**	char16	easy dialogue with supplier
char13	can handle cultural differences		
char2	outsource easy imitable		
char12	culture of continuous improvement		
char26	supplier development		
char19	responsive to market change		
char8	flexible operations		
char10	sharing knowledge		
char24	explorative learning practices		
char23	lean practice		
char6	formal partnership		



PAIRWISE ONLY – 2ND TIER ONLY



	cluster 1		cluster 2
char26	supplier development	char2	outsource easy imitable
char27	monitoring supplier	char16	easy dialogue with supplier
char21	TQM procedures	char5	long term relations
char24	**explorative learning practices**	char3	high level collaboration
char6	**formal partnership**		
char23	lean practice		



APPENDIX O – Case Study of the Three Largest Aerospace Manufacturers (Varga, 2008)

Practitioner

A case-study of the three largest aerospace manufacturing organizations: An exploration of organizational strategy, innovation and evolution

Liz Varga & Peter M. Allen
Cranfield School of Management, Cranfield University, ENG

Many of the most successful firms have placed a strong emphasis on strategy. Strategies help decision-makers in organizations to think through what the organization needs to achieve and how these needs may be satisfied. This case study considers what the Chief Executive Officers of the top three aerospace manufacturers say about their strategies and how these strategies are being implemented. The aerospace manufacturing industry is interesting from a number of respects: its dependence on innovation, its global nature, its relationships with government and other firms, and the different characteristics of the civil and defence markets. This aerospace manufacturing triad is also interesting because of its industry sector coverage: one is a largely defence aerospace manufacturer, the second a largely commercial aerospace manufacturer and the third, an aerospace manufacturer with a balanced portfolio.

Strategies are shifting to take an holistic view of the firm as the firm is increasingly being recognized as a complex system. This holism is particularly evident in the manufacturing firms examined, as they balance innovation, strategy and organizational characteristics in an evolutionary manner. Innovation is fundamental to evolution and this case study employs a novel holistic approach to innovation portfolio assessment. A complex systems perspective is taken for organizational analysis allowing the examination of how fluctuations, resource richness, freedom, capacity to innovate, culture, technology and strategy are balanced and made synergetic. This case study reflects upon how these organizations' strategies are reflected in their organizational forms, their investments in innovations, their performance and ultimately in their potential to evolve.

Strategic perspective

The creation of strategies and acting strategically places a focus on the long term, and the things that are essential for evolution. Anderson (1999) applies complex systems models to strategic management and concludes that this leads to an "emphasis on building systems that can rapidly evolve effective adaptive solutions." Strategic direction requires attention to environments and reconfiguration of organizational architecture to fit anticipated adaptation of agents.

The allocation of resources in line with strategic plans ensures that short-term interruptions do not deflect from long-term goals. However, strategies need to be adaptable to changing circumstances. Exploration is fundamental to adaptation and complexity science provides a theoretical basis for empirical findings, in particular, archetypal patterns of strategy, structure and environment (Maguire, 1999).

Strategy and strategic change itself are influenced by the extent to which leaders believe that it is driven by content (that is structure) and by process. Strategies driven by content are influenced largely by the field of economics and focus is on management activities that aim to achieve predetermined, optimum, rational objectives. These include:

1. The Strategy-Structure-Performance school, concerned with scale, scope and form of organizations;
2. The Structure-Content-Performance school concerned with position and market power, and;
3. Resource-Based View and core competencies.

They are similar in that they make assumption about economic rationality and Newtonian concepts of equilibrium and stability (MacIntosh & MacLean, 1999).

There is now increasing recognition of the importance of key intangible organizational attributes, such as tacit knowledge, learning and intelligence that may signal a more evolutionary view of economics and a demand for a new paradigm focused more on process-driven strategies, essentially challenging the fact that economic rationality should be the primary determinant of strategic behavior. The process-driven school focuses on the extent to which strategy and change are dominated by events and activities that emerge from a wide variety of influences. The school includes: 1. the way that decisions are made, and 2. implementation of strategic change which considers the scope or pace/type and particularly identifies the importance of organizational form with distinct behavioral implications (MacIntosh & MacLean, 1999).

This case study will assess the clarity of long-term goals, resource alignment to long-term goals, the extent of adaptability of the strategy and whether the emphasis in strategic focus is on content (structure) or process, for the three companies that form the substantive focus of the study.

Innovation perspective

In his PhD thesis, Adams (2003) presents an holistic approach to innovation classification. Three innovation types (Readily Adopted, Challenging and Under Cover) form a generalizable framework of innovation, enabling comparison across cases, based on the innovation as the unit of analysis. The benefit of this holistic approach in innovation research is that it enables those items that have traditionally been viewed as discrete (i.e., as multiple attributes) to be meshed in a powerful integrating device. This integrating device is the residue of a thorough analysis of literature research and case study. It ensued from an analysis of descriptions of constructs, construct inter-relationships, organizational contexts, processes from multiple stakeholder perspectives, various data collection methods and levels of analysis. It has enabled the exploitation of the richness of case study (Yin, 2002) and reflected the significance of organizations as complex systems. The analysis provided nomothetic advantages by examining cross-sectional patterns by statistical examination across varying situations (Lucas, 1974) eliminating the lack of generalizability of single cases and enabling generalization to large populations.

Innovation attributes are classified by four first order categories: Newness, Ideation, Application and Benefit (Figure 1).

The interesting result that Adams found was that an extensive study of many different innovation cases led to the identification of essentially only three types of innovation. Considering all the *a priori* possible permutations of the list above (2^{13} if we consider High and Low for each) Adams scores innovations by considering the significance of their underlying innovation attributes. The classification is presented in Figure 2 below. Some innovation attributes are not significant in the classification and are greyed out in Figure 2, others are found to be significantly low or high or not applicable (shown with a dash).

It is the underlying nature of these innovation types that is of primary interest. Adams proposed underlying process characteristics of the innovation types. Readily Adopted innovations have a focus on initiation activities, particularly idea screening and business analysis. Solutions need to mould to local circumstances and the requirement for adaptability is high. The presence of a champion is indicated for Readily Adopted innovations. Challenging innovations are characterized by high ratings for risk, disruption, scope and complexity. They are focused on implementation rather than initiation. Under Cover innovations are notable for an absence of management commitment outside the innovating group although management commitment has been positively associated with innovation success.

There would be considerable interest in examining the reasons why so many potentially possible types are not found. Something like organizational systematics (McKelvey, 1978) or 'cladistic' models (e.g., Allen, *et al*., 2005) may be able to show the incompatibility of certain pairs.

Here, however, we are interested in studying and classifying the innovations identified by the CEOs in their annual reports by evaluating the significance of relevant innovation attributes. The classification allows discussion of the portfolio of innovations which emerges and so the innovation framework is used as a typology facilitating analysis.

First-order Category	Innovation Attribute	Description
Newness	Novelty	The extent of change represented by the innovation compared to what preceded it.
	Departure	The extent of change to existing practice, routines, behaviour.
	Disruption	The extent to which the departure from prevailing practice occurred in a disruptive manner.
	Risk	The extent to which the innovation is inherently risky or threatens individuals, the institution or user base
Ideation	Ideation	Innovation is the consequence of combinations of existing and new knowledge. 3 levels of ideation: 'originated' (wholly original); 'borrowed' (copied, with no modification); 'adapted' (modified to fit the local context).
Application	Uncertainty	Knowledge concerning the link between innovation inputs, processes, and outcomes.
	Scope	The extent to which the innovation stands-alone (within the context of its application), or requires changes elsewhere (outside the group).
	Complexity	The extent to which the innovation, regardless of scope, by dint of its connections (inherent or in terms of other social units) to other parts, renders it difficult to understand and use.
	Adaptability	The extent to which the innovation can be refined, elaborated and modified according to the needs and objectives of the group.
Benefit	Relative Advantage	The extent to which an innovation is perceived as being better than the condition it supersedes.
	Actual operation	The extent to which the innovation is perceived to have satisfied original objectives set for it.
	Observability	The extent to which the innovation is observable by others.
	Profile	The extent to which the innovation raises personal, group or institutional profile.

Figure 1 *Innovation attributes (Adams, 2003)*

Organizational perspective

The third and final perspective contributing to this case study is the organizational perspective which focuses on the evolution potential of each organization.

Complex systems theory is concerned with the perspective of an organization as a nonlinear dynamical system that is continuously probing its own stability with fluctuations of various kinds. Nonlinearity describes the fact that variables are linked by disproportionate responses. This can either be negative in the sense that a fluctuation is dampened, and the previous condition is stable, or it can be positive, in which case a fluctuation can be amplified and can transform the system structure (Allen, 1994).

In any case, a complex system is always fluctuating. Fluctuation is essential for the existence of a complex system, whether it is at the microscopic, macroscopic or any level between. Our observations of fluctuations in the complex system are time-bound and so we cannot say at any one time that the system is stable or otherwise because of the arbitrary long transients that may occur prior to settling on a particular structural attractor. Fluctuations originate from both within and without the organization. One or more of these fluctuations (or perturbations) in some combination are capable of initiating change and evolution in the organization. Most fluctuations are absorbed and so the emergent structures observed at the macroscopic layer as a consequence of the permitted fluctuations are likely to be robust and significant.

When the current stability of the structure of a system is tested for example when a new idea or practice is 'trying' to invade, it encounters a 'fork in the road' or bifurcation point. It is at these points that the system can self-organize through unpredictable leaps into different states (Kauffman, 1991). If the old dominant organizational form or attractor basin can dissipate the force or instability then potential changes fail and the system reverts

First-order Category	Innovation Attribute	Readily Adopted	Challenging	Under Cover
Newness	Novelty			
	Departure			
	Disruption	Low	High	-
	Risk	Low	High	-
Ideation	Ideation			
Application	Uncertainty	-	-	Low
	Scope	-	High	Low
	Complexity	-	High	-
	Adaptability	High	-	-
Benefit	Relative Advantage			
	Actual operation	High	-	Low
	Observability	High	-	Low
	Profile	-	-	Low

Figure 2 *Innovation types (Adams, 2003)*

to a variation of its former state. If the new set of influences takes advantage, the forces or energies go into the formation of a new configuration. Bifurcation points and attractors always exist as latent potentials within any complex nonlinear system and they signal the potentials for self-organization and the evolution of new form.

A stable organization, that is, one not experiencing much fluctuation relative to its attractor basin is not evolving. It may be surviving and perhaps doing so profitably, however its evolution is uncertain. If the organization's resources have requisite variety (Ashby, 1962) and are deployed and exploited for the benefits of the organization during times of environmental change, then the organization may continue to exist. This very existence may consume excessive resources and may not be viable or sustainable in the long term.

Any change to the practices or components within a complex system may influence the extant structural attractor of the system. If some bifurcation point occurs and a different structural attractor emerges, this could become the new norm. Arriving at bifurcation will be due to the new combination of components in the system, which themselves may not yet have settled. The system may re-organize to the new structural attractor if it is 'better' in some qualitative sense than the extant one. Any re-organization is unpredictable and self-organizing because the relationship between components and the system is nonlinear. And in excessively turbulent environmental conditions, hyper-turbulence can overwhelm adaptive capacity beyond management (McCann & Selsky, 1984).

A particularly strong metaphor for evolution is that of the organization as a biological organism (Morgan, 1997). This metaphor captures the view of organizations as living entities and suggests the existence of different species and of variety. It emphasizes the need for ecology, i.e., understanding the inter-relations between organizations and their environments. The metaphor also suggests that the management of organizations can be improved through systematic attention to the needs that must be satisfied for an organization to survive. This focus on needs encourages the insight of organizations as amalgams of interacting characteristics, including those driven by culture, technology and strategy, which have to be balanced in order to survive. Further, the health of the overall system is dependent on the extent of synergy between such interacting characteristics (Allen, 1994).

The importance of organizational form, that is, the particular set of characteristics that makes one organization similar to or different from another organization, is highly applicable to the process of innovation. When a new invention arises either in the environment or in the organization, the organization's capability to innovate (or indeed to decide not to innovate) is dependent on its organizational form. And, this is largely dependent on the path along which it has evolved.

The organizational perspective will form the final part of the analysis framework. Key points for identification are:

1. The fluctuations that exist within each organization and outside it to determine if the organization is evolving or relatively stable;
2. The attractor basins (or latent potentials) in order to suggest how the organization may evolve;
3. Whether each organization's resources have adequate variety to exploit changes in the environment and if the needs are being satisfied systematically;
4. Whether the interacting characteristics of culture, technology and strategy are balanced, and what synergies are present;
5. What capacity the organization has to innovate, and;
6. How its organizational form helps it innovate.

Making these evaluations is limited by the nature of the research. However, the same process is applied without bias to each organization in the case study.

Research method

A grounded, qualitative, inductive approach was taken in examining the public-domain data related to the three organizations in this case study. A breadth in data coverage and data source was the target as the focus on the case study was to identify specific organizational constructs that pertained to evolution. The use of multiple sources permitted some triangulation. However, all data used were public domain, second order data and so my interpretation of this interpreted data will bias my results. My own expectations in using a complex systems lens were to find indications of evolution in:

1. Modularity and de-composability of components, that will increase the overall fitness of the firm and its capability to mutate Simon (2002);
2. Integration and aggregation (Holland, 1995) of components in a synergetic manner (Allen, 1994) that is emergent;
3. Nonlinearity and feedback causing self reinforcing patterns or structures (Arthur, *et al.*, 1987);
4. Self-organization (Kauffman, 1995) and self-reference in the creation of structure through the process of social construction (Hofstadter, 1979) and;
5. Components of systemic survival (diversity, inter-dependence, flexibility, cooperation and partnership, and cyclical flow of resources (Capra, 1996).

The primary source of data collection for the company strategy and innovations of each of these companies was the Chief Executive Officer (CEO) statements in current published annual reports. These reports were coded sentence by sentence using content analysis to identify constructs that each CEO (or his writer) had used to describe the evolution of the firm. These constructs were then organized into themes for each CEO report on a within-case basis by clustering constructs that were similar. The specific words and language used in each CEO statement plus frequency and size devoted to the construct, together with the themes, were analyzed in order to arrive at some conclusions as to the relative importance of evolutionary activity of the firm. The emphasis indicated by the CEO of particular evolutionary activity, for example, by stating that this 'came first' or 'was most significant' was used as a gauge to assess its relative importance to the firm. Each CEO statement was analyzed in this way and triangulated with business reports (via electronic business data sources) regarding these companies. Where anomalies were found between CEO statements and business reports, some scepticism was recorded against the relative importance of the CEO emphasis. In addition, the companies' web-sites were used to obtain further details of each of the innovations mentioned in the annual reports. Cross-case assessment was carried out as the final stage of analysis to explore the differences and similarities between the cases.

Substantive focus

The two primary sectors in the aerospace industry are commercial and defence aviation. Each sector is dominated by two key firms: Boeing and EADS (largely Airbus) in the commercial sector and Boeing and Lockheed Martin in the defence sector (Aerospace Innovation and Growth Team, 2003). Based on figures from their latest annual reports, comparative analysis has been carried out. Note that the figures for EADS are in Euros and that the more recent (2003) Annual Report from Lockheed Martin has been used.

Boeing's revenues are largely equal between the commercial and defense sectors. Boeing's revenues in each sector are roughly equal to that of its main competitors: Boeing's commercial revenue of $28.7bn exceeds that of EADS's commercial revenue of €24bn and Boeing's defence revenue of $25.4bn falls short of Lockheed's defence revenue of $30.1bn. EADS makes 80% if its revenue from the commercial market. Lockheed Martin has 95% of its revenues in the defence market. See Figure 3 for a comparative analysis of revenue. With 166,800 employees, Boeing is by far the largest employer; Lockheed Martin has 130,000 employees and EADS just over 100,000. Figure 4 presents revenue per employee with Boeing achieving the greatest performance. Boeing sold 381 commercial planes and EADS sold 303 in these periods; the number of commercial planes sold per 100,000 commercial employees (determined as the proportion of commercial revenue to total revenue) also shows Boeing as the better performer in Figure 4.

All three organizations aspire to excel, be global leaders or to be the best. With overlapping and competing products, they provide excellent competition for each other.

In commercial aircraft manufacture, manufacturers must produce very high quality, reliable airplanes at competitive prices. Technological innovation and feature differentiation are very desirable but it is more important to remain competitive. Access to global markets and manufacturing process technology is also vitally important. In defence aircraft manufacture, manufacturers must offer aircraft with innovative features that are technologically more advanced. Cost is not of primary concern. Design secrecy is highly important and the prime customer is usually the home country's Government (Antoine, *et al.*, 2003).

Boeing

Boeing is the largest aerospace manufacturer with turnover twice that of its nearest competitor. Global revenues were $51.1 billion in 2002 of which 53% were generated from Boeing Commercial Airplanes and 47% from Integrated Defense Systems (Boeing, 2003). The commercial/defence portfolio mix has changed markedly since 1993 when 80% was generated from the commer-

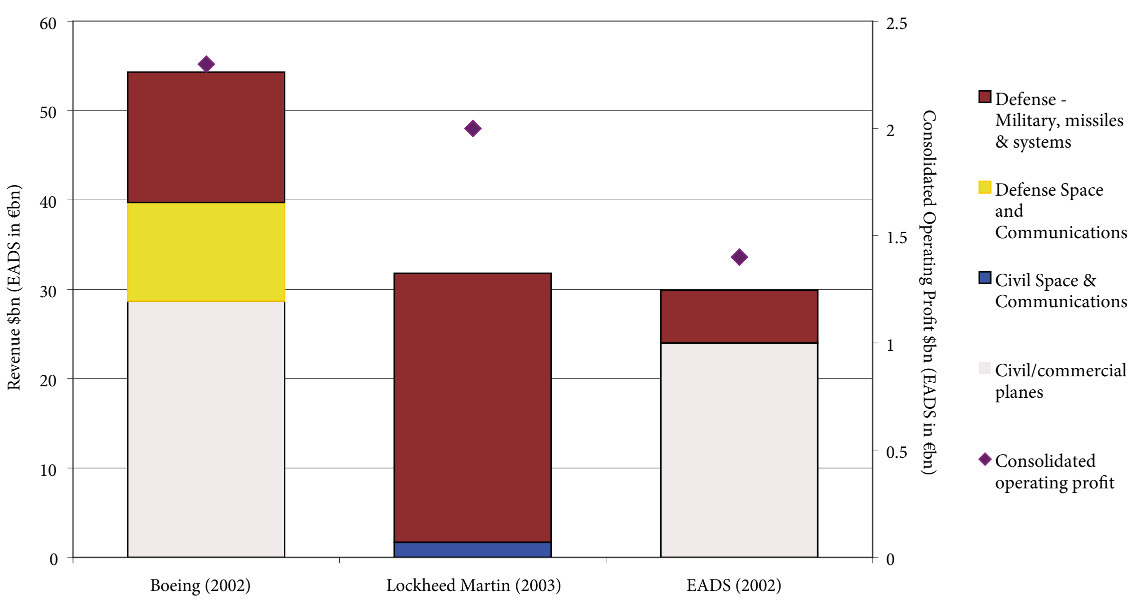


Figure 3 *Comparative analysis of revenue and operating profit*

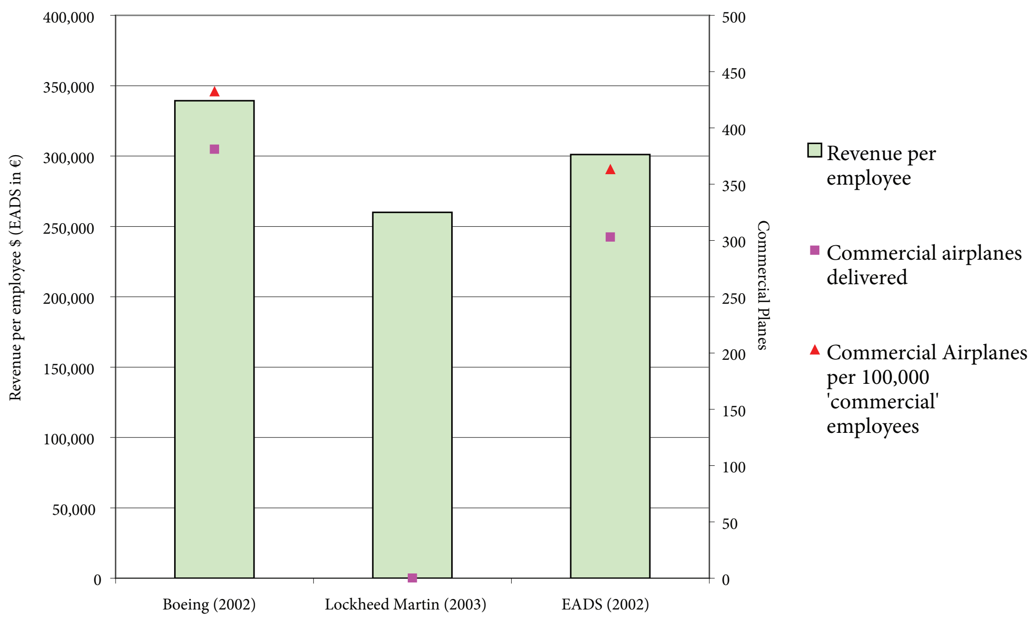


Figure 4 *Performance per employee*

cial market. Philip Condit was the Chairman and CEO at the time of the annual report publication but resigned on 1st Dec 2003 at age 62 marking the end of 7 years at the helm. Condit's resignation followed shortly after his firing of the Chief Financial Officer for alleged unethical practices and the July 2003 punishment by the Pentagon for possessing 35,000 pages of stolen Lockheed Martin documents (Business Week, 2004). A class action accusing Boeing of underpaying female employees and denying them promotions was set to the largest sex-discrimination lawsuit ever to go on trial but has since been settled out of court (Seattle Post Intelligencer, 2004). New CEO Harry Stonecipher is the retired Boeing president aged 67, and was chief of McDonnell Douglas when Boeing bought it in 1997 (Time Canada, 2003). Condit, recognized as a brilliant engineer, moved Boeing from Seattle to Chicago in 2001 (Fortune: Europe, 2003).

Philip Condit's statement in the Annual Report (Boeing, 2003) is entitled "Defining the Future" which has immediate focus on the evolution of the industry. He covers three explicit topics: Strategy, Execution and Markets.

Condit desires Boeing's strategy to be adequately abstract so as not to have to change frequently. The strategy is to "Excel in All Principal Aerospace Markets." This has meant creating a diversified company "of unrivalled breadth and balance." Boeing perceives balance providing greater stability, strength and agility and to this end they have created a company with 'balanced' revenue from civil and defence markets. With this diversification comes compromise since each market segment is likely to provide variable levels of profitability and whereas one segment's profit might smooth another's loss, overall, profitability cannot be maximal. Condit also retains a technical focus to Boeing's Strategy requiring the delivery of outstanding performance. Company growth is also identified. The strategy itself has three parts:

1. Run healthy core businesses, no exceptions and no excuses;
2. Leverage our strengths to enter new markets where we have the customer knowledge or the technology to make an immediate impact;
3. Open new frontiers in aerospace with the potential to transform the future.

Boeing put operations first, entering existing markets where they have competencies next and developing new markets last. This is a risk-averse profile, limiting feedback and self-organization.

Condit's description of Boeing 'execution' is centered on customer and investor satisfaction, by "reliability and excellence in financial performance as well as technical performance." The importance of meeting expectations and taking immediate and decisive action is highlighted, an example being to match capacity to demand following 9/11. The Boeing expectation is of further reductions in commercial airplane deliveries. Lean manufacturing and the introduction of moving lines have reduced final assembly times, an innovation focussed on efficiency improvement and cost reduction, but evidencing integration and aggregation.

Concurrent investment in the future of the business is demonstrated by investment in the new 7E7 and derivatives of existing planes, the Extended Range 747-400ER and 777-300ER.

Condit states that the "best companies … shape the markets of tomorrow." He recognizes the different characteristics of commercial and non-commercial markets. For commercial aviation and space he notes the prolonged downturn. For defence and non-commercial space, the markets are strong and growing. Condit demonstrates Boeing's market shaping by the creation of the city-to-city non-stop low-cost and convenience market fragment they have created by airplane range performance improvements, having exploited opportunities in regulatory liberalization.

Condit identifies Boeing Connexion and Boeing Air Traffic Management businesses as having "the potential to transform the future of flight." Integration in the defence arena is offering "tremendous opportunities … in a networked world of interoperable platforms and systems." Boeing's re-organization of military aircraft and missile systems, space and communications businesses into a single organization, Boeing Integrated Defence Systems, demonstrates Boeing's own belief in integration.

In Condit's concluding remarks, he looks to the future for Boeing. The anticipation is for solid financial results, demonstrating the balance that the portfolio mix is having for Boeing. Condit answers his own question: "Why am I confident of the future of the Boeing Company?" His answers are: 1. great people, 2. right strategy, 3. good execution, 4. shaping markets of tomorrow, and 5. character and integrity of the company. Although 'great people' are cited first, his strategy does not mention the investment in learning and innovation that Boeing provide. These include the Learning Together Programme which is underpinned by Boeing's Vision 2016 to have the best educated workforce in the world, and the Chairman's Innovation Initiative which identifies new business concepts and spin-outs and expansion of the intellectual property portfolio by generating new invention disclosures and patent application.

According to Adams's (2003) innovation

Innovation	Sector	Newness	Application	Benefit	Innovation Type
Boeing Connexion	Commercial	Low	-	High	Readily Adopted
Delta IV booster	Defence	High	High	-	Challenging
Ground-based Midcourse Defense program	Defence	High	High	-	Challenging
X-45A Unmanned Combat Air Vehicle	Defence	High	High	-	Challenging
Boeing Air Traffic Management	Commercial	-	Low	Low	Under Cover
747-400ER (extended range)	Commercial	Low	Low	Low	Under Cover
777-300ER	Commercial	Low	Low	Low	Under Cover
Boeing 7E7 (bulk of R&D in Commercial Airplanes)	Commercial	-	-	Low	Under Cover
Lean manufacturing (and moving lines) Commercial Airplanes	Commercial	Low	-	Low	Under Cover

Figure 5 *Boeing innovations*

framework, Figure 5 below is presented as an analysis of the innovations identified in the Boeing annual report (2003). The innovation types were determined following an assessment of the apparent significance of the innovation attributes (disruption, uncertainty, etc. – see Figure 2) as discussed in Boeing's annual report. Each innovation could be classified by Innovation Type. A discussion appears after the EADS and Lockheed Martin summaries.

EADS

EADS is the second largest aerospace and defence company with turnover of €29.9 billion (European Aeronautic Defence and Space Company EADS N.V., 2002). With 1 Euro worth around 1.04 USD, the exchange rate was close to par at the end of 2002. The Euro is now stronger and exchanges for approximately 1.28 USD (2006). Around 80% of EADS revenues arise from the commercial market to which Airbus contributes significantly. EADS are moving towards an expected financial recovery.

EADS, with head-offices in France and Germany, has two Chief Executive Officers – Philippe Camus and Rainer Hertrich. A recent article, one of a very few relating to EADS, finds Camus endorsing the creation of a European armament, military capabilities and research agency to combat tighter US technology transfer restrictions (Aviation Week & Space Technology, 2003).

The "Message from the CEOs" in the Annual Report is organized into a question and answer format. It covers the EADS activity in three markets – Defence, Civil and Space – and then explores the strengths and strategy of EADS.

Although the building up of the defence side of EADS is a strategic priority, the CEOs recognise the nature of defence projects as long-term and subject to political change. Completed projects include the creation of MBDA, the 2nd largest missile systems company in the world. The importance of partnership is recognized and include partnerships with BAE Systems and Finmeccanica. Preferred bidder status with the UK MoD (Ministry of Defence) is expected to help their breakthrough into all European Markets and even NATO. The creation of North American EADS is expected to improve market access to the US and particularly to gain access to US technology. These comments from the CEOs recognise the need for systemic survival, in particular co-operation and partnerships.

The CEOs note that the A400M programme in Germany is expected to "trigger synergies with Airbus civil activities." The Airbus fleet has a unique advantage of operational commonality, leading to savings for operators in terms of crew training and improved efficiency and flexibility. This recognizes the need for modularity in complex systems.

The Civil market is described as lackluster, driving production down 22% to 303 aircraft albeit up on market share. The down-cycle is harsh and unpredictable, but Airbus state that they are in better shape than ever to manage it, particularly by productivity improvements and benefits of scale. Development of the very large future aircraft A380 is self-financed, entering peak R&D and capital expenditures. Increased demand for Eurocopter places it holding 60% of market share in this segment.

Space business is the most challenging for EADS, suffering from both over-capacity and lower demand. EADS's launcher business is directly affected by the difficult satellite telecommunications market and by the problems with the new Ariane 5 ESCA launcher that are being worked on. Opportunities are expected to deliver in programmes like Paradigm and Galileo.

The strategy for global leadership has been pursued successfully, despite the difficult environment, due largely to EADS's capacity to react and adjust to uncertainties and the building of a strong, united company. A clear vision over growth is expected via EADS International, which supports marketing around the world, and works across divisional boundaries. EADS is ambitious to achieve and maintain global leadership, but also to take a realistic approach recognizing the unpredictable nature of the world. The CEOs recognise that feedback occurs and there is need for flexibility. Tactics are to look for cost savings and cash generation where growth is not available and to give demanding development targets where growth prospects exist. EADS recognizes its main strengths as successful products and quality of their people.

Figure 6 below is presented as an analysis of EADS's innovations using the same innovation framework and method as for the Boeing assess-

Innovation	Commercial/ Defence	Newness	Application	Benefit	Innovation Type
555-seat A380, largest ever civil aircraft	Commercial	High	High	High	Challenging
Ariane 5 ESCA launcher	Commercial	High	High	High	Challenging
A400M military transport	Defence	High	High	-	Challenging
Air Re-fuelling Boom System Development	Defence	High	High	-	Challenging
CN-235 with FITS (Fully Integrated Tactical Mission System)	Defence	High	High	-	Challenging
Tiger military helicopter & NH90 military transport helicopter	Defence	High	High	-	Challenging
Eurofighter combat aircraft	Defence	High	High	-	Challenging
Missiles – Meteor, Aster & Storm Shadow	Defence	High	High	-	Challenging
Galileo satellite navigation system	Defence	High	High	-	Challenging
Paradigm space-based defence communication	Defence	High	High	-	Challenging
A340-500/600 ultra long-range	Commercial	Low	Low	Low	Under Cover
A318 – 100 seater regional airliner	Commercial	-	-	Low	Under Cover

Figure 6 *EADS innovations*

ment. The discussion appears after the Lockheed Martin summary.

Lockheed Martin

Lockheed Martin Corporation is the third largest aerospace manufacturer with turnover of $31.8 billion in 2003 (Lockheed Martin Corporation, 2003). 95% of their business is in the defence market. Lockheed Martin CEO Vance D. Coffman was named Chairman on 24th April, 1998, succeeding Norman R. Augustine who remained a director (The Wall Street Journal: Eastern Edition, 1998). Coffman retired on 6th August, 2004, and Robert Stevens has taken over as CEO.

At the top of Lockheed's priorities is customer satisfaction as stated by Coffman in the Annual Report. This is aided by the creation of Integrated Systems & Solutions and the Global Vision Network that are enabling collaboration among customers and Lockheed. Lockheed are keen to manage expectations and note that, as a government contractor, they are subject to oversight but that Government indemnification does not cover all risks.

The commercial launch vehicle market place is recognized as very competitive with low demand for new satellites and excess capacity in the telecommunications industry. Opportunities are identified in space exploration. Defence business, in particular military missions and reconstruction in Iraq and Afghanistan, is strong. The emphasis on homeland security is expected to increase demand for Lockheed's capabilities in air traffic management, ports and waterways security, biohazard detection systems for postal equipment and information systems' security.

Lockheed has sold its commercial IT business to ACS in a transaction where Lockheed bought the defence and most of the civil government IT business from ACS. There is apparent focus on

Innovation	Commercial/ Defence	Newness	Application	Benefit	Innovation Type
E-government solutions	Defence (Civil)	Low	-	High	Readily Adopted
Patriot Advanced Capacity (PAC-3) missile	Defence	High	High	-	Challenging
Atlas V (or EELV) launcher	Commercial Defence	High	High	-	Challenging
F/A-22 Raptor	Defence	-	-	Low	Under Cover
F-35 Joint Strike Fighter	Defence	High	High	-	Challenging
Spitzer Space Telescope	Defence	High	High	-	Challenging
Joint Air to Surface Standoff Missile	Defence	High	High	-	Challenging
Global Vision Network	Defence	Low	-	High	Readily Adopted
ACS transaction	Defence	-	Low	Low	Under Cover
Titan acquisition	Defence	-	-	Low	Under Cover
LM21 (process improvement and lean manufacturing)	Defence	Low	-	Low	Under Cover

Figure 7 *Lockheed Martin innovations*

network-centric solutions for defence and national security customers and on Citizen-centred civil government solutions using capabilities in critical intelligence, knowledge management and e-Government. Both these solution types recognise the need for integration of complex systems. There is expected growth in business-process outsourcing due to legislative change in public/private competitions and from the government in upgrading and investing in new information technology systems and solutions. Lockheed are continuing to focus resources in support of infrastructure modernisation, allowing interoperability and communication across agencies. Finally, opportunities are also identified through organizational changes, where Lockheed can leverage technical expertise across the organization.

Market focus is demonstrated by the reorganization of Lockheed's business areas to address the "changing and increasingly complex needs of our defense customers, especially in the critical area of Information Superiority." Lockheed's focus as a lead systems integrator recognizes the emerging priority of the US Department of Defense towards "joint operations, net-centric command and control and integrated capabilities of the armed forces."

Innovation is evident in the multiplicity of solutions. Globalization and internationalization is demonstrated by the creation of the "Global Vision Network ... and the Global Vision Integration Center in Suffolk, Virginia." The skills of "this innovative corporation of 130,000 dedicated men and women… who bring a passion for invention" and recognition that a "diverse and talented workforce is fundamentally important to our future competitiveness"; and "superior development processes (and process improvement)."

Customer satisfaction and operational performance are high on the list of priorities. These are achieved by recruitment and retention of the best people, the use of efficient methods, such as lean manufacturing techniques, the importance of values to inspire the management team and ethics and the importance of social responsibility.

Coffman's vision for Lockheed to be the "best advanced technology systems integrator" is consistent with the focus in resources. Coffman reflects on the successful execution of their strategy of disciplined growth evidenced with a third straight year of positive momentum in sales and operating profit. Coffman is now handing over and is "confident that the future of Lockheed Martin is indeed bright and the best years are ahead."

Figure 7 above is presented as an analysis of Lockheed's innovations using the same innovation framework and method as for the Boeing assessment. The discussion appears below.

Just one year prior to his handover of the chairmanship to Coffman, Augustine handed over the CEO reigns to Coffman. At this time he offered 12 suggestions for the survival of the US defence industry (Augustine, 1997). These suggestions are identifiable and aligned with Coffman's final CEO statement. Coffman's recognition of the importance of social responsibility is the only item Augustine does not mention.

Discussion

Boeing's move from 80/20 commercial/defence revenues in 1993 (roughly the same as EADS has in 2002) to 53/47 in 2002 is consistent with the strategy of reducing dependence on the cyclical commercial airplane market. However, it is fortuitous that Boeing had reduced its exposure to the commercial market by the time of the 2001 terrorist attack in New York that prompted a significant downturn in civilian travel but an upturn in the defence market. Boeing's resources had adequate variety to exploit the changes in the environment and were aligned with the change. Further demands for integrated solutions in the defence market have prompted a re-organization within Boeing and the creation of a new business unit that should help it to innovate further. This is particularly important in the defence market. In terms of strategic thinking, Boeing's strategy is driven by content/structure and traditional economic rationality.

An analysis of Boeing's 9 innovations reveals Boeing's focus in the commercial market. 67% of its innovations are in the commercial sector although its revenues from this sector amount to only 53%. This can indicate its desire to strengthen its commercial market position. All 3 defence innovations are Challenging innovations, indicating a focus on implementation. There is an absence of Readily Adopted innovations in the defence industry innovations which signals a search for generic defence solutions rather than locally customizable innovations. All bar one of the remaining 6 innovations are Under Cover innovations. Adams (2003) found an absence of management commitment (outside the innovating group) in Under Cover innovations and if the same is true for these innovations, there are implications for Boeing given the number of such innovations, assuming that the assessment of innovation type is correct. Only one innovation is Readily Adopted and this is in the Commercial sector. This indicates that there is a product champion for Boeing Connexion and that it is highly adaptable innovation.

There is evidence that interacting practices of culture, technology and strategy are balanced however Condit does not mention that Boeing are building a Global Enterprise (Boeing, 2003). Also, its investments in technology-focussed venture capital funds are not reviewed by the CEO and these are potentially key sources of innovative strength. How these fit with 'Execution' is also not clear. The strategy does not consider how market demand for commercial and military aircraft may change in the medium and long-term. If the safety and security features being developed now are implemented in the short-term and more people are encouraged to fly, then the mix should will favor commercial aircraft in the medium-term. In the long-term however, commercial flight may be significantly curtailed because of escalating environmental conditions aggravated by airplane emissions. Homeland defence demand is unlikely to be curtailed in this way. Boeing's strategy for a balanced portfolio will keep options open to them.

Perturbations within Boeing include the dismissal of the Chief Finance Officer and the resignation of the CEO. This is particularly poignant as the CEO described the importance of integrity in his annual statement. These departures are likely to push Boeing into a new evolutionary direction. The resurrection of retired Boeing president

Stonecipher as the new CEO will be a holding position that is intended to bring some stability in the light of outstanding actions and thus will pull Boeing back to its existing attractor basin. This move will stifle evolution and enforce risk aversion. Until a new CEO is appointed Boeing is unlikely to evolve.

EADS is vulnerable to the lower demands for civil airplanes and satellites/launchers because of its exposure to this market segment. These fluctuations outside the organization are reflected in the cutting back of production and greater need for productivity efficiencies within EADS. There is some mitigation due to successful growth in the defence market and in the Eurocopter. Overall, EADS is unlikely to be in a stable situation and it is likely that structural attractors favoring the defence market and customized personal transport (such as the Eurocopter) will be stronger.

An analysis of EADS's innovations highlights the company's focus on defence market implementation. For an organization that achieves 80% of its revenue from the commercial sector, only 33% of its innovations are in the commercial sector. This indicates the company's push into the Defence market. Of the 12 innovations, 10 are Challenging innovations, and all innovations in the defence market are Challenging innovations. Of the 4 commercial innovations, 2 are Under Cover innovations; these are the long-range and the regional airplane projects. The absence of Readily Adopted innovations could indicate the lack of product champions in EADS. The innovation portfolio is unbalanced across innovation types and across markets signalling the potential for significant internal fluctuation.

EADS is exposed to the civil airplane market, however it has weathered storms before and can perhaps withstand fluctuations in demand. Culture and technology appear to be balanced and a strategy to grow defence using innovative staff is synergetic. This demonstrates a more process-driven strategy. The organization invests substantially in research and development and obtains grants for research. If progress in the space market does not materialise, there will be a structural attractor away from this work and maintaining a position in this market will be difficult.

In the medium-term, the structural attractor of the civil airplane market is likely to strengthen for EADS as security improves and demand increases, particularly for long-haul cheap flights. The A380 may arrive with perfect timing, but will require the adaptive ability of the organization to exploit it fully. In the long-term, the growth of the defence (and space) business is the only area for evolution, and this is already reflected by the focus on defence market innovations.

Lockheed Martin has experienced significant recent growth of nearly 20% in 2003 and 11% in 2002. This is a reflection of the demand in defence and military aircraft and the capability of Lockheed Martin to deliver to demand. This strengthens the structural attractor that demands innovative staff. The organization has also recognized two major new drivers for change – the demand for integration systems and the civil government agenda for electronic service delivery. These have been recognized by acquisitions (and disposals) which strengthen the capacity of the organization to evolve in this direction.

An analysis of Lockheed's innovations presents a balanced innovation type portfolio. All 11 innovations are focused on the Defence market, although the Atlas V launcher can be used in the commercial market. There are two Readily Adopted innovations, which focus on initiation and have high adaptability. There are 5 Challenging innovations that are highly product focussed and demand implementation attention. There are 4 Under Cover innovations, which demonstrate an absence of management commitment outside the innovating group and interestingly these are focussed more on process innovation.

Lockheed recognizes the increasing complexity of the needs of their defence customers, particularly with respect to information superiority. Lockheed is addressing this by organizational changes to their workforce. There is evidence of content-driven strategy, for example, the creation of Integrated Systems & Solutions and the Global Vision Network, but there is also some evidence of process-driven strategy and the encouragement of behaviors that will enable organizational forms to develop. Culture, technology and strategy are closely balanced and provide synergies. The recent departure of the CEO will bring an internal fluctuation which could cause the organization to evolve in a new direction or more rapidly into integrated systems. Long-term the current growth rates are

	Boeing	Lockheed Martin	EADS
STRATEGY			
Clear long-term goals	Medium	Medium	Medium
Resources aligned	High	Medium	Medium
Adaptable	Medium	Medium	High
Content (structure) focus	High	Medium	Medium
Process focus	Low	Medium	High
INNOVATION			
Commercial			
Cost leadership focus	High	Low	High
Market access	High	High	Medium
Manufacturing process technology	High	Medium	High
Commercial Innovations %	67%	5%	33%
Defence			
Advanced technology	Medium	High	Medium
Home country government link	High	High	Medium
Defence Innovations %	33%	95%	67%
Readily Adopted Innovations (initiation focus) %	11%	18%	0%
Challenging Innovations (implementation focus) %	33%	46%	83%
Under Cover Innovations (management commitment query) %	56%	36%	17%
Alignment of innovations to long-term goals	Medium	High	High
ORGANIZATION			
Extent of fluctuations	Medium	Low	High
Adequate variety and needs satisfied systematically	Medium	High	Medium
Balance of culture, technology and strategy	Medium	High	Medium
Level of synergy	Low	Medium	High
Form and capability to innovate	Medium	High	High
Latent Potentials	Low	Medium	Medium
EVOLUTION			
Extent of potential evolution visible	Low	Medium	High

Figure *8 Triad relative assessment*

unlikely to be achieved as defence and military needs reduce. The development of integrated systems may provide the structural attractor for evolution.

Conclusions and limitations

Figure 8 below summaries the strategy, innovation and organizational perspectives reviewed in this case study. The assessments are relative to the companies examined (not absolute values), and were interpreted from the text of the company annual reports. There is no 'right' assessment for any of these criteria since they are contextual.

Boeing maintains that a balanced portfolio across defence and civil markets has given it stability, strength and agility by the creation of a diversified company. But with diversification comes integration cost which EADS has dealt with somewhat in its approach to operational commonality. EADS is looking to increase its share of the defence market so that it achieves 30% (from 20%) of revenue from defence and is innovating aggressively to achieve this. Lockheed is almost entirely in the defence market, although there is clearly much activity in integrated systems , both within the military and civil government. Boeing too have reorganized around the integration scenario although their's appears to be a structural integration rather than a technological integration. As at 2002/3 most profits were made from the defence market and so EADS suffered most, and recognizes its need to improve its exposure to the defence market.

Each supplier is exploring one or more market niches: Boeing Connexion and Boeing Air Traffic Management projects; EADS's Missile systems and Eurocopter, plus the A380; Lockheed Martin's Global Vision Network and e-Government solutions.

Operational demands for performance and efficiency are evident for all suppliers. EADS had adapted is production levels and is improving efficiency in its civil business. Boeing is focussed on financial and technical performance and on taking immediate action on market changes. Lockheed Martin states the need for operational performance and efficient methods but these diminish under the focus of innovation and growth opportunities. Boeing and EADS are both relatively agile as has been demonstrated by action to respond to reduced market demand. EADS's desire for agility is reflected in the frustration it feels at the anticipated long-term quest to penetrate the US defence market. Lockheed Martin shows less agility and more risk awareness and aversion although these are balanced somewhat by a passion for innovation. Boeing is also passionate about innovating and opening new frontiers, but its first priority is to run healthy core businesses.

In terms of differences, EADS is the only organization that mentions partnerships and is using these particularly to gain access to wider markets. EADS is the only one to recognise synergies explicitly from defence across to Airbus. Lockheed Martin is the only one engaged in acquisitions and disposals. Lockheed Martin is alone in its explicit corporate social responsibility statement.

EADS appears to be placing most energy into evolution, and is most process focused in its strategic outlook. As such, it may evolve most significantly. In particular, developments as a consequence of its 555-seater plane, and its push for defence market share provide significant latent potentials. Boeing is likely to stagnate in the short to medium-term as it redefines its corporate identity under new leadership. Its commercial market operational focus and innovation portfolio is inhibiting significant innovation. Lockheed Martin is currently evolving successfully because of defence market demand, but this is likely to peak and may contract in the long-term. Civil government and integrated solutions could provide Lockheed's new evolutionary pathway.

This case study has explored the evolutionary potentials of the three largest aerospace manufacturers by evaluating strategic focus, innovation portfolio and organization potential for evolution. Both within-case and cross-case evaluations have been carried out based on public information within mostly Company Annual Reports. My contribution has extended Adams's (2003) work into a new organizational context.

Further research could explore these organizations' innovations more deeply and perhaps create a matrix of innovations for each organization enabling a more accurate analysis of innovation portfolios. The analysis of the innovations in the three annual reports is limited by the innovations specifically identified by the CEOs and by their descriptions of these innovations. Those working in the companies would be able to provide comprehensive details of all innovations and would be better able to classify them (according to Adams) resulting in a more accurate analysis. In particular a large limitation of the research is that the amount of investment or emphasis placed on each innovation is taken as equal, where in practice this is unlikely to be the case. The authors do not have access to the detailed spend on each innovation nor its importance with regard to the evolution and sustainability of the firms, therefore the conclusions are somewhat speculative. The relationships between the innovations and organizational forms of each of these companies could be studied to identify more clearly the developing latent potentials. Unexplored environmental factors could also be considered.

Although the source text is indisputable, the authors' interpretation of the text may differ from either the intended interpretation or a consensus of constructions of the text. To moderate this, the organizations themselves could rate the assessments of their organizations, strategies and innovations and indicate whether they perceive the same constructs and evaluations as the authors. Other raters, both with a complexity lens and with other lenses, for example, resource-based view or contingency perspective, could rate the annual reports and consider evolutionary potential. These analyses would provide a richer more meaningful interpretation. In any event, the source text is confirmable (capable of being tested and verified by access to the public documents) and the process used for analysis in the study is consistent and repeatable (Miles & Huberman, 1994). As our understanding of complex systems evolves, we are likely to produce different results over time.

The value of the organizational analysis is limited to the complex adaptive systems perspective. The evolutionary approach taken and, in particular, identification of what might lead to bifurcation points for these companies, is subjective.

There is limited generalizability from the sample of aerospace manufacturers to all aerospace manufacturers since it is the largest 3 firms that are examined and so are not representative of the population as whole. There are strictly limited inferences that can be made about motivation or intent as a consequence of the content analysis. A larger, quantitative study of the industry could ameliorate sample limitations.

Application of the innovation framework (Adams, 2003) is potentially limited for the aerospace industry since innovation types were concluded from research into NHS innovations. The NHS is the largest employer in the UK and organized into many departments and services. This does not compare in size, location or industry sector to aerospace and so it is likely that the innovation framework would have at least some differences in morphology if it had been conducted in aerospace firms. However, if confirmed, the innovation framework provides a valuable, integrated insight into a key aspect of organization evolution, that of innovation.

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