

## **Sustainable Supply Networks: A Complex Systems Perspective**

### ***Abstract***

A complex adaptive systems perspective is used to examine the sustainability of the supply network in the commercial aerospace manufacturing sector. A framework for the analysis of coevolutionary dynamical change is used which examines the structure, integration methods and process dynamics within the supply network. Multiple methods are used for data collection from 8 firms in the sector. The framework identifies 14 management implications related closely to the sector's current heterarchical supply network archetype. The management implications address known environmental factors for the sector and the broader techno-economic paradigm.

### ***Key words***

Coevolution, Commercial Aerospace, Environment, Structure, Integration, Dynamics

## Introduction

Significant changes have been observed in the structure and dynamics of supply networks over the last 20 years, driven by changes in the environment and by the firms within the supply networks. This paper recognises firms, supply networks, and the environment as complex adaptive systems (Choi et al., 2001). A paradigm shift to a complex adaptive systems view and a coevolutionary dynamical epistemology of supply networks holds promise for future research addressing Daft and Lewin's (1993) observation that firms are changing cataclysmically with respect to networks and that a new theory of supply networks is needed (Salancik, 1995). This shift also gives primacy to 'organizational becoming' (Tsoukas and Chia, 2002) and a new way to approach change.

The paper starts with an introduction to the tenets of complexity science, and how they apply to supply networks. It is followed by a description of the market and environmental context of jetliner manufacturing in order to place the firm and the supply network with the current eco-historical regime (Garnsey and McGlade, 2006). This includes a brief history of the demand for jetliners, followed by the identification of relevant global technological change, ending in a discussion of the current environment influences for the industrial sector: global connectedness, technology know-how, customer expectations (for quality, cost, and security), competition and 'regulations and legislation'. The case study methodology is described next followed by the case study results which are presented in the order of structure, integration methods and process dynamics of the supply network. Results from the case study, synthesized with the current environment raise the most relevant management implications for the

sustainability of commercial aerospace supply networks. A discussion follows with suggestions for further research.

### ***Multi-Layer Complex Adaptive Systems***

Complex adaptive systems are the structuring mechanisms, integration methods and associated process dynamics which adapt, have emergent properties and are open to their environments (Varga, 2009). 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). A complex system does not act in isolation (Barabasi, 2002).

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). Existing structures are the consequence of the irreversibility and path-dependency of the supply network and of the organizations, past and present, within the supply network. Experimentation is important (Allen, 1988) as innovations and evolutions fit within the wider milieu of the social, cultural, environmental and technological of their own history: the “*eco-historical regime*” (Garnsey and McGlade, 2006).

Each organization’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. As a result of these relationships, dynamic network constraints and benefits occur (Gulati, Nohria and Zaheer, 2000), e.g. benefits of lock-in

to a profitable network or lock-out of a failing network. Conversely, the constraints can act disadvantageously, e.g. lock-out of profits and lock-in to a failing network.

Small differences in market share can be amplified and develop into much larger differences (Arthur, 1994) so long as self-reinforcing processes, that is positive feedback, dominates self limiting processes or negative feedback which act as a self-regulatory mechanism and the key to equilibrium (Capra, 1996). 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).

The supply network has matured through a number of observable stages (see Table 1): from connecting intra-organizational components of inbound materials and outbound products; to dyadic (two-sided) supplier relationships in which each organization attempts to manage immediate suppliers; to dyadic chains which extend the relationships of the organization 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. This paper adds the supply network as a complex adaptive system in which coevolution occurs between the firms and the supply network, in the context of the environment.

[Table 1 about here]

Supply networks are recognized as innately dynamic, responsive to the environment and constituted from the complex adaptive systems at the levels below. They are complex

adaptive systems, which have variations and are selected for in particular environments as they coevolve with other complex adaptive systems.

## **The Environment Of Commercial Aerospace Manufacturing**

This section describes the environment of commercial aerospace manufacturing by examining the products of the sector, the global techno-economic paradigm and current environmental influences.

### ***The Products: Jetliners***

Modern day commercial airliners or jetliners are used to carry large numbers of passengers on medium and long-haul journeys across the globe. The firms examined in this paper produce jetliners carrying at least 100 passengers. These planes are powered by turbofan jet engines which are relatively quiet and fuel-efficient when compared to first generation of jetliners such as the de Havilland Comet and Douglas DC-8. Such jetliners 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.

By 1977, over 30 years ago, the Boeing 727 fleet had carried its one billionth (1,000,000,000) passenger, a first achieved by a commercial aircraft. Today the number is in excess of 4 billion. The 727 was the first best-selling jetliner 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, 2008).

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

The Boeing and Airbus fleets 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 in 1974) number 5,545 (EADS Airbus, 2008). Airbus has delivered more jetliners than Boeing since 2003 and 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).

Only a small number of jetliner 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). The jetliners are distinguishable by size: wide body/2 aisle and narrow/single aisle. 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 (16,745), a third of which are Boeing 737s. The jetliners which continue in production are easily identified in Table 2 as those with a to-date which indicates the cumulative count at that point.

[Table 2 about here]

Variants of commercial jetliners sometimes exist for the transport of freight. Other adaptations include that for VIP corporate use, typically where the jetliner 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 paper however the versatility of many jetliners has contributed to their longevity, for example, the Boeing 737.

### ***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, 1994) or Kondratiev’s macroeconomic cycles (Kondratiev, 1984), these paradigms describe the dominant or standard ways of economic development over different time periods. Their relevance is to highlight new generic technologies driving renovation and innovation leading to new economic models through waves of creative destruction (Schumpeter, 1994). These globalization paradigms are consolidated in Table 3. The first globalization included four “logics” of production: water power, steam power, electricity; and oil.

[Table 3 about here]

The earliest dominant “logic” was the harnessing of water power via canals in the period from the 1770s. This coincides with Schumpeter’s 1<sup>st</sup> 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 2<sup>nd</sup> 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 3<sup>rd</sup> Schumpeter wave.

The fourth "logic" was the age of oil and the new technologies of the 20<sup>th</sup> 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 4<sup>th</sup> wave. After 1940s, jet airplanes enabled managers to travel regularly to distant plants.

The 2<sup>nd</sup> 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 5<sup>th</sup> which highlights the growth in digital networks and software.

The 3<sup>rd</sup> 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 3<sup>rd</sup> globalization or Schumpeter's V<sup>th</sup> 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.

### ***Environmental Influences***

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

### **Global Connectedness**

The transition from a national-regional logic to a global-local one (Longhi, 2005) is evidenced in changes at Toulouse, the European capital of the commercial aerospace industry. 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).

### **Technological Know-How**

The dominant technologies in jetliner production are the jet engine and composite materials. 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. Whilst this configuration is still used on some short and medium haul planes, design of jetliners has converged to a low-wing design with 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.

Composites are advantageous due to light weight, and so good for fuel consumption, and strength, however they are more complex to manufacture than most metal structures and are difficult to repair and detect faults. Collaborative knowledge sharing in the recent developments in composite materials shows the value of out of sector knowledge for aerospace (McAdam et al., 2008). In the recent A380, composites form 25% of the airframe by weight, including the central wing box although the fuselage is aluminium.

### **Customer Expectations**

At the start of the 21<sup>st</sup> century, the severe knocks to the global commercial aerospace industry following 9/11 (New York), SARS (originating in China) 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, although traditionally the success of jetliner models and the firms producing them 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 (and the power to ground aircraft) are critical to customer confidence in selecting flight travel.

Air traffic has now fully recovered from the impacts of 9/11 and 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. Other social changes, such as the growth in obesity due to energy dense food, motorised transport and sedentary lifestyles (Foresight, 2007).

### **Competition**

Government protectionism is observed in two ways. Statutory instruments or laws are sometimes created, supporting industry restructuring and consolidation, enabling them to compete globally, but also preventing 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 jetliners 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).

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). The location of developing skills and knowledge, particularly in great numbers in China and Russia will be a source of competition for the west.

### **Regulations And Legislation**

The effects of flight travel continue to influence the industry. The need to reduce CO<sub>2</sub> emissions and 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, and rising air passenger duty. Other environmental concerns range from aircraft noise, to fuel consumption and the need for energy efficiency, improved infrastructure and land use. Compliance is required by firms with a range of environmental legislation (SBAC, 2001). 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 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 (Gonzalez, 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 focussed 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.

## **Summary**

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 (SBAC, 2001).

## **The Case Study**

This section presents the research methodology and the case study results.

## ***Research Methodology***

A case study approach has been chosen because it is well suited to new research areas (Eisenhardt, 1989) or when new perspectives 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 a 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 interview methods of data collection 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).

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 the rationale for organizing the supply network in its current form. The repertory grid technique creates qualitative interview data and matrices of quantitative data conjointly (Goffin, 2002). Within a rep grid design, it must be decided what the columns will be beforehand. Two rep grid designs

were used: the first with customers and the second with suppliers, in order to look downstream and up-stream respectively, in the supply network.

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). Nevertheless, firm selection was driven more by opportunism than planned theoretical or selective sampling. 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’*. In all, 8 firms who are significant in commercial aerospace manufacturing were the subject of the case studies.

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 and all interviews were typed-up into electronic format (MS Word) providing a permanent record of the research.

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. 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). In addition, 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).

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 coding categorization. Constructs and principal components identified in the qualitative and quantitative data from structured repertory grid interviews was incorporated into the analysis.

Once the coding was completed from the different methods of collection, a comparison was made against literature. Those categories which were found using multiple interview methods and were verified in extant literature were selected for this paper. The whole process from research design, through data collection, analysis and comparison with literature enables grounded theory to be developed (Pandit, 1996).

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.

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.

### ***Analysis of Case Studies***

Key aspects of the structuring, integration and dynamics (Varga, 2009) within the commercial aerospace manufacturing sector are examined in these case studies with respect to sustainability in the supply network, summarized in Table 4.

[Table 4 about here]

Sustainability for the commercial aerospace manufacturing sector is measured for the purposes of this paper, as the maintenance of current total firm revenue relating to the production of jetliners. This definition permits flexibility in three ways. First, manufacturing capacity may be located anywhere in the world and so revenue is not nationalistic allowing competitive positions to change globally and the sector to remain sustainable. Second, if more jetliners are produced at lower cost, then total revenue of the sector can be maintained whilst also meeting demand for more flights. Third, it is assumed that current and future environmental demands can be met by new technologies, better designs and new methods whilst maintaining quality and safety requirements without incurring price rises.

## **Structuring Of The Supply Network For Sustainability**

There are two key themes in the structuring of the supply network for sustainability. The first theme is that of globalization and the second is related to product complexity-cum-miniaturization.

### **Globalization**

The primary factor in the structuring of the commercial aerospace manufacturing supply network is increased globalization. Global connectedness for a variety of purposes is converging to a wide geographical dispersion of suppliers. There is a tangible global division of labour as noted in the current techno-economic paradigm. Reasons for globalization include access to skills for innovation, low costs for manufacturing, and access to global markets for sales.

**Access To Skills:** The diminishing and narrow diversity of aerospace engineers in the West is in contrast to the East where there are young and growing skills, is likely to move the locus of innovation to the East as noted in current environmental influences. Very few new individuals enter the aerospace industry. Engineering graduates choose different industries, so existing aerospace engineers move between firms. Skills need to be found globally.

MI (Management Implication):<sup>1</sup> Develop relationships, educational, R&D, etc. around the world, promoting own product training, researching new technologies and allowing non-linear effects (Lorenz, 1963) to work.

**Low Cost Manufacturing:** 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. But lower costs have in the past been associated with firm immaturity with respect to other capabilities, such as quality and delivery precision.

MI:2 Outsourcing can create resilience to demand fluctuations but the cost is resources to manage and develop suppliers to attain quality and other performance standards. Outsourcing also creates diversity in the supply chain and can lead to innovation and positive feedback.

**Access To Global Markets:** The loyalty of airlines to home country manufacturers has changed over the last 30 years. Nowadays, there is global competition for local customer business. There is no longer national loyalty. Competition is global so need to sell globally but government restrictions can act as constraints. For example, the exports of some commercial jetliners have required export licences which have not been readily granted to some countries in the past. In terms of environmental influences, there has been investment in infrastructure in the East and growing competition.

MI:3 Know the implications for export of the components and technologies used in the jetliner. Some global markets which will form the long-term market for jetliners may have under-developed transport infrastructure and industrial skills for the service and maintenance of jetliners. These are opportunities for developing relationships and shaping future markets, but it is likely that these countries will demand a level of in-country manufacture. The implication is that the next generation of jetliners is likely to use the same manufacturing and assembly plants and will produce for other nations.

The balance of cooperation (and permissible 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, Dooley and Rungtusanatham, 2001)

### **Product Complexity-Cum-Miniaturization**

The secondary factor in the structuring of the commercial aerospace manufacturing supply network is increased product complexity and miniaturization leading to increased specialization of suppliers into product systems or specialist products, and a move away from the generalist firm. Product complexity has also driven increased consolidation of suppliers. Finally, the primes driven demanded complete systems of their first tier suppliers, leading to systematization, and the redefined role of the 1<sup>st</sup> tier as systems specialists and OEMs. As the first tier produce system, so component design work has shifted up the supply network.

**Specialization:** Increased specialization has driven the requirement for an increased customer base, providing global resilience during market demand fluctuations. 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. *“We used to be our own supplier in a lot of ways. Primes owned many more manufacturing facilities then and do much less manufacturing now. Nowadays, primes prefer their suppliers to have other customers to help spread the long term involvement in business risk”*. This industry diversification means new customers are able to exert power, creating pressure for timely delivery of the commodities demanded by the aerospace firms.

MI:4 Control over suppliers is no longer possible as the specialist systems suppliers could now have much bigger customers. Relationship and partnership development is needed and new ways for mutual collaboration and integration.

**Consolidation:** Demand fluctuation and the reduction of in-house manufacturing has led to vertical disintegration and increased consolidation of firms. Consolidation has led to less diversity and less choice in the supply network; the network has become less dense. This strengthens the market position of the consolidated firm. The supply network archetype is that of a heterarchy in which collaboration is key as control is diminished. When the consolidated firm is brought on board to a new supply network, the firm is likely to stay in the supply network for the life-time of the product. *“When you choose that supplier you pretty much marry to him on that programme. So the supplier selection has evolved, and is almost all upfront. We essentially take into account market access. We take into account access to capital market, access to technology...”* Once a product/model is established, the organization is locked in, or vertically integrated, to a supply network (Gulati et al, 2000). However at the lower part of the supply chain at the commodity level it is much more competitive. Short relationships come under more evaluation.

MI:5 Partnership is a way of collaborating between key and non-key suppliers, but skills in partnership (and relationship) creation and maintenance need to be learned .

Consolidation of firms can lead to a fragmented organization with multiple businesses producing similar products; reorganization along product line rather than business line would improve specialization and variety.

**Systematization:** Increased product complexity has led to simplification by the notion of systematization. Suppliers who were previously 1st tier (to the primes) are now consolidated or working for the new 1st tier systems' integrators to produce integrated systems. Integration work previously carried out by the primes has moved to the 1st tier diminishing their detailed knowledge of system design. The role of systems integrator is a competitive position of engineering and integration expertise. Functional complementarity of network partners can be achieved in which specialist skills and capabilities are provided by relevant network members (Parkhe, 1991). Suppliers further down the chain will become increasingly commoditized and will have to compete on price. Systematization is an example of a nearly decomposable system in which the rates of interaction between components at one level of the hierarchy are higher than those between different components (Simon, 2002)(Levin, 2002).

MI:6 Systematization improves the rate of evolution making the system fitter, so is to be encouraged in order to find higher performing bundles of components. IPR ownership moves to the OEM but advanced design and build skills are needed for integrated systems.

### **Integration Of The Supply Network For Sustainability**

Integration is concerned with protocols, methods and enablers that permit two or more firms to communicate and deliver their obligations. There are three themes in the integration of the supply network for sustainability. The first theme is that of standard interfaces, the second is related to technology, the third is that of quality standards.

**Standard Interfaces:** 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. Quality standards

MI:7 Firms should contribute to the shared development of standard interfaces, learning from other industries as necessary. Project teams could be constituted from the customer, integrator and supplier to develop solutions creating integrated designs, rather than bi-lateral ones.

Technology: The ability to use a global ICT infrastructure and shared systems is as important for product development as it is for production planning and delivery. Networks and distributed computing is a continually improving general purpose technology and resource allowing shared systems to be accessed from any location around the world. Broad-band and real-time communications is a distinct feature of the 3rd globalization/Schumpeter's V<sup>th</sup> wave. Supply chain management has shifted to IT (Ho, Au and Newton, 2003). Primes have developed portals in their design and engineering system that enables them to work with suppliers, researchers and partners on a integrated basis, enabling high-speed data transfer of high-level digital information supporting virtual working on fairly complex environment of 3D CAD. Computing tools are incredibly powerful and driving significantly changing relationships with suppliers. "Suppliers need to be organized for efficiency of manufacturing but also for information and collaboration". The use of technology to automate production can reduce resource requirements and act as an alternative to outsourcing to LCEs.

MI:8 Technology integration of a global nature attempts to overcome cultural, language and distance differences. Skills are needed to use the appropriate technologies, but

also to prevent information/knowledge sharing leakages and vulnerabilities.

Technological solutions may provide alternatives to outsourcing.

**Quality Standards:** Maintaining and improving quality standards is critical within the sector and drives supplier selection. Expectations of supplier quality performance have never been higher, particularly of risk-sharing partners, who may be supported by supplier development programmes. Suppliers are likely to be classified by quality standard, so that the highest quality suppliers are offered new work first. Certificated aerospace manufacturers are limited in numbers, have very high performance but very high cost.

MI:9 There is a cost associated with quality dependent on the skills of the supplier.

Quality needs to be learned, particularly by new firms in the supply network.

### **Coevolutionary Dynamics Of The Supply Network For Sustainability**

This aspect of the supply network sustainability looks at the processes dynamics which are carried out within the structure of the supply network and using the integration methods. These process dynamics of the firm coevolve with the supply network, in the context of the environment.

The dynamics of the commercial aerospace supply network appear to be Janusian – having two faces – one related to the formative stages of the supply network and the second related to the operational supply network. Five key themes emerge, each of which has two faces: these are innovation, market responsiveness, information sharing, supplier performance and risk mitigation.

**Innovation:** Radical innovation occurs for new products in new supply networks, although suppliers will invest R&D funds on technology research which may not be usable for some time. Engineering designs largely stagnate once a jetliner is in production; a focus on production process technologies can create a competitive edge for manufacturers. The creation of 'blurred technologies' for improvements in current production are desirable. New jetliner designs must increasingly accommodate requirements for lower CO<sub>2</sub> emissions and improved fuel efficiency, and incorporate manufacturing demands in their design. These are environmental influences, some of which are regulatory or legislative. Increased terrorism activity increases the need for product security innovation measures.

MI:10 Process innovation is key in operational supply networks, whereas product innovation is key for new supply networks. Both can contribute to increased sustainability by addressing energy and resource use, and improve flight safety.

**Market Responsiveness:** Customer demand for jetliners halved in a three year period then recovered in a three year period witnessed between 2000 and 2008. In operational supply networks this has been achieved through vertical disintegration, supplier consolidation and supplier specialization and diversification. Demand for new jetliners is based on product concepts using strategic marketing methods. The order book for commercial aerospace can have a 2 year backlog. Although demand has been high and growing since 2006, there is a global financial crisis which is likely to have some impact on commercial air travel. Demand fluctuations may be a recurrent theme in commercial aerospace manufacturing.

MI:11 Structural agility is more easily met through heterarchical or temporary structures must be maintained in order to meet demand fluctuations. Diversifying into other related sectors or industries may be an option.

**Information Sharing:** Information sharing is largely translucent in product design rather than transparent in the operational supply network. Translucency is sometimes a consequence of sharing product designs before they are finalized but can be intentional, as too much transparency may give away information to competitors, although OEMs are particularly aware of this risk. Mutual sharing of information is believed to give better warning of fluctuations in demand and avoid some of the bull-whip effect, however premature or incomplete sharing of information can also cause production delays in operational supply networks.

MI:12 Mutual and timely information sharing and appropriate dialogue is perceived as beneficial. Management techniques should be developed and used.

**Supplier Performance:** Development of suppliers affects not only the performance of the supplier but the performance of the supply network. In particular the adoption of quality management techniques, Just-in-Time, Kanban, and lean techniques to name a few, can reduce rework, cut stock holding levels, improve responsiveness to demand fluctuations and improve the supplier's chances for selection in new supply networks. The resource costs associated with the support of learning and development in 'low cost economies' are high and demand long-term commitment particularly from 1<sup>st</sup> tier organizations. *"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...  
Some of that is a long time commitment. It takes a lot of resources and energy."*

MI:13 The firm should invest in supplier development and recognize supplier performance. Increased quality performance has often been driven by industrial change, particularly from automotive manufacturing.

**Risk Mitigation:** When the firm cannot exercise direct control (via ownership) over the supplier, then methods are required to ensure that the risks of failure are mitigated. Limited numbers of suppliers are available for most parts and whilst double sourcing is possible, it is not always cost effective for the management of operational risks. In terms of suppliers, their risk of failure or bankruptcy is a risk to the Prime, so risk is managed by understanding mutual interests and responsibilities in a partnership capacity. Partnering also helps to influence sales and to create shared investments. Firm dominance over suppliers can be asserted in a collaborative way rather than in a control manner.

MI: 14 There needs to be a balance between risk and cost to mitigate risk. 'Templates' which achieve defined outcomes can be useful, collaborative techniques which provide sufficient flexibility.

These 14 management implications are summarized in Table 4.

## **Discussion**

The supply network of the commercial aerospace manufacturing sector is dominated by a duopoly of Boeing and Airbus. The current supply network archetype is that of a

heterarchy. The issue of influencing independently owned firms within a heterarchy requires coordination mechanisms. Management implications identified in the case study were strongly connected to coordination and collaboration as a means to achieve stated objectives.

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).

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 Van, 1994). However, 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 and 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 chain partners making inter-company cooperation difficult (Kärkkäinen, Holmström, Främling and Artto, 2003).

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. Organizations 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. 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, Lambert et al, 1997) in a non-equilibrium manner.

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, Gunasekaran et al, 2004). A supply network can be defined as a group of semi-independent firms which collaborate in “ever-changing constellations” in order to achieve some business goal related to the collaboration (Akkermans, 2001; Tapscott, 1996).

### ***Further Research***

The research identified the growing importance of product service and ‘flight by the hour’ as a likely future business model. The transformations required to the current supply network archetype and its structural mechanisms, integration methods and coevolutionary process dynamics would be valuable research for practice and policy. Further research which incorporates a broader industry survey would be useful for practice.

If environmental concerns heighten and accelerate the need for new products then research into whether the existing supply network archetype is able to deliver considerably more jetliners per year would be valuable research. Currently the rate of change in the environment is running at a slower rate than change in the firm and supply network. If this is reversed then according to the Red Queen effect (Van Valen, 1973; Kauffman, 1995; Barnett and Hansen, 1996) the firm and the supply network will not be able to evolve unless it continues to develop just in order to “maintain its fitness” relative to the systems it is co-evolving with. This speeding up of environmental relative to socio-economic change is interesting for practice and research.

A comparative research pathway would be to examine and compare alternative supply network archetypes for the purposes of sustainability, such as the market, hierarchy, Kieretsu and 4PL™ (Varga, 2009). Finally, the research design and in particular the mixed methods research strategy could be attempted in other fields to examine coevolutionary dynamics, integration methods and structural mechanisms of another industry or sector.



<b>Stage of development</b>	<b>Type of trading relationship</b>	<b>References</b>
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, James P. and Jones, 1990; Womack, 2002) (Davis, 1993)
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, DeWitt, Keebler, Min, Nix and Zach, 2001) (Larson and Rogers, 1998) (Christopher , 2005; Christopher, 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 and Vokurka, 1999) (Bowersox, Closs, Stank, 2000)
Complex Adaptive Supply Network	Complex Adaptive System; emergent and coordinated; embedded in its environment and eco-historical regime; non-linear effects and feedback; multi-layer coevolutionary system with structure, integration and dynamic	(Surana et al., 2005) (Choi et al., 2001) (Kauffman, 1993) (Garnsey and McGlade, 2006) (Holland, 1998; Arthur, 1994) (Varga, 2009)

Table 1  
*Developments in Supply Network Explanation*

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
<b>United States &amp; Canada</b>									
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	
<b>South America</b>									
Embraer (Brazil)	Embraer					E-jets: E-170, E-175, E-190, E-195	2002 -	446	30/09/2008
<b>Europe</b>									
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	
<b>Russia</b>									
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
<b>Totals</b>				5808				16745	

Table 2  
Jetliner Models and Deliveries

<b>Dominant “logics” of production/ techno-economic paradigms</b>	<b>“Standard way of doing business,” utilizing the new generic key technology</b>	<b>Schumpeter’s waves</b>
Canals and availability of water power, new infrastructures from 1770s	mechanized work	<b>Schumpeter I</b> 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	<b>Schumpeter II</b> 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	<b>Schumpeter III</b> wide use of the electricity; development of internal-combustion engines; start of chemical industries from 1900s
Age of Oil, Automobile and Mass Production from 20 <sup>th</sup> century  End of 1 <sup>st</sup> 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	<b>Schumpeter IV</b> rise of petrochemical products from oil and gas; development of electronics and aviation industries
Age of Information & Telecommunications (or the Information Society)  2 <sup>nd</sup> 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	<b>Schumpeter V</b> growth of digital networks, software and the new media
3 <sup>rd</sup> globalization	Broadband communications network, global division of labour; internet-based business models, real-time virtual service	

Table 3  
*Globalization Paradigms adapted from Tuomi (2007) and Schumpeter (1994)*

Dimension	Category	Sub-category	Management implication
Structural Mechanisms	Globalization	Access to skills for innovation	MI:1 Develop relationships, educational, R&D, etc. around the world, promoting own product training, researching new technologies, allowing non-linear effects to work.
		Low cost manufacturing	MI:2 Outsourcing can create resilience to demand fluctuations but the cost is resources to manage and develop suppliers. Outsourcing also creates diversity in the supply chain and can lead to innovation and positive feedback.
		Access to global markets	MI:3 Know the implications for export of the components and technologies used in the jetliner. Develop relationships with LCEs and help shape future markets.
	Product complexity-cum-miniaturization	Specialization	MI:4 Control over suppliers is no longer possible as the specialist systems suppliers could now have much bigger customers. Relationship and partnership development is needed and new ways for mutual collaboration and integration.
		Consolidation	MI:5 Skills in partnership (and relationship) creation and maintenance need to be learned. Consolidation of firms may require reorganization along product line rather than business line to improve specialization and variety.
		Systematization	MI:6 Systematization improves the rate of evolution making the system fitter, so is to be encouraged in order to find higher performing bundles of components. Advanced design and build skills are needed for integrated systems.
Integration Methods	Standard interfaces	MI:7 Firms should contribute to the shared development of standard interfaces, learning from other industries as necessary. Project teams could be constituted to develop solutions creating integrated designs, rather than bi-lateral ones.	
	Technology	MI:8 Technology integration skills are needed to use the appropriate technologies, but also to prevent information/knowledge sharing leakages and vulnerabilities. Technological solutions may provide alternatives to outsourcing.	
	Quality Standards	MI:9 There is a cost associated with quality dependent on the skills of the supplier. Quality needs to be learned, particularly by new firms in the supply network.	
Coevolutionary process dynamics	Innovation	MI:10 Process innovation is key in operational supply networks, whereas product innovation is key for new supply networks.	
	Market Responsiveness	MI:11 Structural agility is more easily met through heterarchical or temporary structures must be maintained in order to meet demand fluctuations. Diversifying into other related sectors or industries may be an option.	
	Information Sharing	MI:12 Mutual and timely information sharing and appropriate dialogue is perceived as beneficial. Management techniques should be developed and used.	
	Supplier performance	MI:13 The firm should invest in supplier development and recognize supplier performance. Increased quality performance has often been driven by industrial change, particularly from automotive manufacturing.	
	Risk mitigation	MI: 14 There needs to be a balance between risk and cost to mitigate risk. 'Templates' which achieve defined outcomes can be a useful collaborative technique which provide sufficient flexibility.	

Table 4  
*Summary of Management Implication by coevolutionary theme and category*

## **References**

Air Transport Action Group (2008), *Air Transport & the Environment*, available at:

<http://www.atag.org/files/AirTransportEnvironmentFlyer.pdf>.

Airsafe (2008), *Airliner Crash Rates*, available at:

[http://www.airsafe.com/events/models/rate\\_mod.htm](http://www.airsafe.com/events/models/rate_mod.htm).

Akkermans, H. (2001), "Emergent Supply Networks: System Dynamics Simulation of Adaptive Supply Agents", *System Sciences: Proceedings of the 34th Hawaii International Conference on 3-6 Jan 2001*.

Arthur, W. B. (1994), *Increasing Returns and Path Dependence in the Economy*, ISBN 0472064967, University of Michigan Press, Ann Arbor.

Asia Times (2006), *China Renews Airliner Manufacturing Plan*, available at:

[http://www.atimes.com/atimes/China\\_Business/HC14Cb07.html](http://www.atimes.com/atimes/China_Business/HC14Cb07.html).

Assa, O. and Denton-Brown, J. (2008), *The Future of Airport Growth*, available at:

<http://www.sovereign-publications.com/bechtel.htm>.

Barabasi, A. (2002), *Linked: The New Science of Networks*, ISBN 0738206679, Perseus Books Group, New York.

Barnett, W. P. and Hansen, M. T. (1996), "The Red Queen in Organizational Evolution", *Strategic Management Journal*, ISSN: 1097-0266, 17: 139-157.

Boeing Website (2008), *Boeing Commercial Deliveries*, available at:

<http://active.boeing.com/commercial/orders/index.cfm?content=userdefinedselection.cfm&pageid=m15527>.

Castells, M. (1996), *The Rise of the Network Society*, ISBN: 1557866171, Blackwell Publishers, Oxford.

Choi, T. Y., Dooley, K. J. and Rungtusanatham, M. (2001), "Supply Networks and Complex Adaptive Systems: Control Versus Emergence", *Journal of Operations Management*, ISSN: 1758-9398, 19(3): 351-366.

Crump, E., ( 2009), Airbus still the world's biggest maker of planes; Final 2008 orders total set to edge Boeing, *Daily Post*, Liverpool, UK, available at:

<http://www.dailypost.co.uk>

Daft, R. L. and Lewin, A. Y. (1993), "Where are the Theories for the "New" Organizational Forms? An Editorial Essay", *Organization Science*, ISSN: 1047-7039, 4(4): i.

Department for Transport (2005), *Civil Aviation Bill*, available at:

<http://www.dft.gov.uk/about/strategy/whitepapers/air/cab/civilaviationbill>.

DTI Aerospace and Defence Directorate (2003), *Aerospace and Defence Technology Report 2002/3*, available at: <http://www.berr.gov.uk/files/file10022.pdf>

EADS Airbus (2008), *Airbus orders and deliveries*, available at:

[http://www.airbus.com/en/corporate/orders\\_and\\_deliveries/](http://www.airbus.com/en/corporate/orders_and_deliveries/).

- Easterby-Smith, M., Thorpe, R. and Lowe, A. (eds) (1994), *Management Research: an Introduction*, ISBN: 0761972846, Sage Publications Ltd, London.
- Eisenhardt, K. M. (1991), "Better Stories and Better Constructs: the Case for Rigour and Comparative Logic", *Academy of Management Review*, ISSN: 0363-7425, 16(3): 620-627.
- Eisenhardt, K. M. (1989), "Building Theories from Case Study Research", *Academy of Management Review*, ISSN: 0363-7425, 14(4): 532-550.
- Epstein, K. and Crown, J. (2008), "Globalization Bites Boeing", *Business Week*, ISSN: 0007-7135, 4076: 32.
- Foresight (2007), *Social Foresight*, available at:  
<http://s3.amazonaws.com/foresight/20.pdf>.
- Freeola (2008), *Boeing 727*, available at: <http://www.century-of-flight.freeola.com/Aviation%20history/coming%20of%20age/Boeing%20727.htm>.
- Garnsey, E. and McGlade, J. (2006), *Complexity and Co-evolution: Continuity and Change in Socio-economic Systems*, ISBN: 184542140X, Edward Elgar Publishing, Cheltenham, UK.
- Gates, D. (2006), "Clean engines, wings that fold: Boeing dreams of futuristic jets", *Seattle Times*, ISSN: 0745-9696.
- Goffin, K. (2002), "Repertory Grid Technique", in Partington, D. (ed.) *Essential Skills for Management Research*, ISBN: 0761970088, Sage Publications, Trowbridge, Wilts, UK.

- Gonzalez, A. (2007), "To go Green in Jet Fuel, Boeing Looks at Algae", *Seattle Times*, ISSN: 0745-9696.
- Hamel, J., Dufour, S. and Fortin, D. (1993), *Case Study Methods*, ISBN: 0803954166, Sage, Newbury Park, CA.
- Ho, D. C. K., Au, K. F. and Newton, E. (2003), "The Process and Consequences of Supply Side Virtualization", *Industrial Management + Data Systems*, ISSN: 0263-5577, 103(5): 423-433.
- Holland, J. (1998), *Emergence: From Chaos to Order*, ISBN: 0201149435, Perseus Books, Cambridge, MA.
- Kauffman, S. A. (1995), "Escaping the Red Queen Effect", *The McKinsey Quarterly*, ISSN: 0047-5394, 1: 119-129.
- Kauffman, S. A. (1993), *The Origins of Order*, ISBN: 0195079515, Oxford University Press, New York.
- Kondratiev, N. (1984), *The Long Wave Cycle (translated from The Major Economic Cycles, originally published in Russian in 1925)*, ISBN: 0943940079, Richardson & Snyder, New York.
- Levin, S. A. (2002), "Complex Adaptive Systems", *Bulletin (New Series) of the American Mathematical Society*, ISSN: 1088-9485, 40(1): 3-19.
- Lewis, M. A. (2003), "Analysing Organizational Competence: Implications for the Management of Operations", *International Journal of Operations & Production Management*, ISSN: 0144-3577, 23(7): 731-756.

- Longhi, C. (2005), "A French Revolution: Technology Management in the Aerospace Industry The case of Toulouse", *International Journal of Technology Management*, ISSN: 1741-5276, 29(3/4): 194-215.
- Lorenz, E. N. (1963), "Deterministic Nonperiodic Flow", *Journal of the Atmospheric Sciences*, ISSN: 0022-4928, 20: 30-141.
- McAdam, R., O'Hare, T. and Moffett, S. (2008), "Collaborative Knowledge Sharing in Composite New Product Development: An Aerospace Study", *Technovation*, ISSN: 0166-4972, 28(5): 245-256.
- Mulford, C. L. and Rogers, D. L. (1982), "Definition and Models" in Rogers, D. L. and Whetten, D. A. (eds.); *Interorganizational Coordination; Theory, Research and Implementation*, ISBN: 081380986X, Iowa State University Press, Ames.
- Pandit, N. R. (1996), "The Creation of Theory: A Recent Application of the Grounded Theory Method", *The Qualitative Report*, ISSN 1052-0147, 2(4).
- Parkhe, A. (1991), "Interfirm Diversity, Organizational Learning, and Longevity in Global Strategic Alliances", *Journal of International Business Studies*, ISSN: 1478-6990, 22(4): 579-601.
- Pastore, R. (2004), "A Failure to Collaborate?" *CIO*, ISSN: 0894-9301, 17(19): 14.
- Patton, M. Q. (1987), *How to use Qualitative Methods in Evaluation*, ISBN: 0803931298, Sage Publications, Newbury Park, California.
- Patton, M. Q. (1990), *Qualitative Evaluation and Research Methods*, ISBN: 0803937792, Sage Publications, Inc, Newbury Park, CA.

- Pettigrew, A. (1990), "Longitudinal Field Research on Change: Theory and Practice", *Organization Science*, ISSN: 1526-5455, 1(3): 267-292.
- Ragin, C. C. (2000), *Fuzzy-Set Social Science*, ISBN: 0226702774, University of Chicago Press, Chicago, IL.
- Ragin, C. C. (1987), "Case Oriented Comparative Method", in Ragin, C. C. (ed.) *The Comparative Method: Moving Beyond Qualitative and Quantitative Method*, ISBN: 0520066189, University of California Press, Berkeley, pp. 34-52.
- Rungtusanatham, M. J., Choi, T. Y., Hollingworth, D. G., Wu, Z. and Forza, C. (2003), "Survey Research in Operations Management; Historical Analyses", *Journal of Operations Management*, 21: 475-488.
- Salancik, G. R. (1995), "Wanted: A Good Network Theory of Organization", *Administrative Science Quarterly*, ISSN: 0001-8392, 40(2): 343-349.
- SBAC (2001), *Air Travel Challenge: Greener by Design*, available at:  
[http://www.foresight.gov.uk/Defence%20Aerospace/Air\\_Travel\\_Challenge\\_Aug\\_2001.pdf](http://www.foresight.gov.uk/Defence%20Aerospace/Air_Travel_Challenge_Aug_2001.pdf).
- Schumpeter, J. A. (1994), *Capitalism, Socialism and Democracy (originally published in 1942)*, ISBN: 0415107628, Routledge, New York.
- Simon, H. A. (2002), "Near Decomposability and the Speed of Evolution", *Industrial and Corporate Change*, ISSN: 0960-6491, 11(3): 587-599.

Strauss, A. and Corbin, J. M. (1990), *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*, ISBN: 0803932510, Sage Publications Inc, Newbury Park, CA.

Surana, A., Kumara, S., Greaves, M. and Raghavan, U. N. (2005), "Supply-chain networks: a complex adaptive systems perspective", *International Journal of Production Research*, ISSN: 1366-588X, 43(20): 4235-4265.

Tapscott, D. (1996), *The Digital Economy: Promise and Peril In The Age of Networked Intelligence*, ISBN: 0070633428, McGraw Hill, New York.

Tsoukas, H. and Chia, R. (2002), "On Organizational Becoming: Rethinking Organizational Change", *Organization Science*, ISSN: 1047-7039, 13(5): 567-582.

Tuomi, I. (2007), "Learning in the Age of Networked Intelligence", *European Journal of Education*, ISSN: 1465-3435, 42(2): 235-254.

Van Valen, L. (1973), "A New Evolutionary Law", *Evolutionary Theory*, ISSN: 0093-4755, 1: 1-30.

Varga, L. (2009), *The Coevolution Of The Firm And The Supply Network: A Complex Systems Perspective* (unpublished PhD thesis), Cranfield University, Cranfield University.

Williamson, J., Dooley, K. J. and Corman, S. (2004), "Using Text Mining to Create Actionable Knowledge: Application to Network Failure Incident Reports", in Karagiannis, D. and Reimer, U. (eds.) *Practical Aspects of Knowledge Management*, ISBN 3540240884, Springer, Berlin, pp. 71-81.

Yin, R. K. (1984), *Case Study Research: Design and Methods*, ISBN: 080392058X, Sage, Beverly Hills, CA.

Yusuf, Y. Y., Gunasekaran, A., Adeleye, E. O. and Sivayoganathan, K. (2004), "Agile Supply Chain Capabilities: Determinants of Competitive Objectives", *European Journal of Operational Research*, ISSN: 0377-2217, 159: 379-392.

-