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INVESTIGATION OF STRATEGIC CAPACITY ISSUES IN THE AEROSPACE SECTOR

by

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Abstract:

The business environment is changing fast and radically. Traditional capacity planning has limitations in today's dynamic environments, particularly from a strategic perspective in the aerospace sector. This document sets out to identify the unique characteristics of the aerospace industry and compare the traditional views of capacity planning and modern concepts in SCP relevant to the sector. Key findings are summarised from an analysis of the literature on strategic capacity planning. The importance of considering demand uncertainty, technology uncertainty and supply uncertainty is highlighted. Two case studies in the aero-engine sector are presented. A collaborative virtual organisation requires Strategic Capacity Planning (SCP) that focuses not only on economies of scale but also on coordination, flexibility and responsiveness. An integrated framework for addressing SCP in the aerospace industry is presented.

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GLOSSARY OF TERMS

OEM: Original Equipment Manufacturer

RSP: Risk-Revenue Sharing Partner

SCM: Supply Chain Management

SCP: Strategic Capacity Planning

VAC: Volvo Aero Corporation

EXECUTIVE SUMMARY

Traditional capacity planning has limitations in today's dynamic environments, particularly from a strategic perspective in the aerospace sector. In this deliverable, Strategic Capacity Planning (SCP) is studied with the aim of developing a framework for coordinated capacity planning in a virtual organisation in the aerospace sector. The objective of the extended enterprise is to develop an integrated network with all supply chain participants to promote flexibility, responsiveness and lean production. The challenge of SCP is to plan and control the capacity between the OEM and its upstream suppliers and downstream customers in order to maximise the value of the entire supply chain.

The report summarises key findings from an analysis of the literature on strategic capacity planning. Capacity planning may be faced with three uncertainties: (i) demand uncertainty, (ii) technology uncertainty, and (iii) supply uncertainty.

An SCP framework is presented here incorporating four major issues to understand future business scenarios and capacity dynamics.

- Sharing information and integrating business processes
- Building trust and retaining control
- Balancing outsourcing and vertical integration
- Establishing supply chain contracts

Based on two case studies conducted with the aero-engine industry, the following issues are highlighted:

- Supply uncertainty should encourage capacity reservation to secure reliable and continuous supply.
- Demand uncertainty requires capacity outsourcing to reduce the significant upfront capital investment and investment risks.
- Technology uncertainty encourages process innovation to simplify the production process.
- Integration and automation of information systems facilitates collaboration between supply chain participants to achieve synchronised capacity planning.
- Balancing trust and power can offset supply chain uncertainty and forgo one-to-one relationship in a virtual organisation.

1 INTRODUCTION

1.1 BACKGROUND – THE AEROSPACE INDUSTRY

The aerospace industry is characterised as an oligopoly with high barriers to entry where a small number of aerospace manufacturers compete to maximise profits over a fixed planning horizon (Nolan and Zhang, 2003). As high-tech manufacturers, they must deal with capital-intensive facilities, highly skilled labour, long manufacturing lead-times, and continuous technological innovation (Jin and Wu, 2001). As a cyclical industry with unpredictable commercial cycles, many factors influence the pattern of new aircraft orders (Bramham et al, 2004).

While capacity planning is important for any manufacturing company, a few factors make this problem especially critical to the aerospace industry. Firstly, capacity planning is complicated by the large commitments to functional capabilities under conditions of uncertainty, such as R&D, manufacturing expertise, and investments in many different kinds of resources. In addition, capacity expansion decisions need to be made far in advance due to the high cost and long-lead times required. Karabuk and Wu (2003) note that if the capacity is not expanded in a timely fashion to meet market demands, a significant loss of market share may result.

A second factor that complicates capacity planning in the aerospace sector is new technology development and manufacturing process improvement. The variability of new technology may lead to uncertainty in capacity estimation and throughput (Karabuk and Wu, 2003). If capacity cannot be utilised to deliver orders on time, it can lead to very undesirable business consequences. On the other hand improvements in productivity can be anticipated but may be difficult to estimate with precision over a long planning horizon.

A third factor affecting the aerospace industry is the unprecedented growth and external uncertainties in government regulation, economic conditions and green technology, which require managerial flexibility (Datamonitor, 2006). For these reasons manufacturers in the aerospace industry have increased their use of cooperative agreements such as joint ventures and risk-revenue sharing in the value chain system to collaborate on the development work and in manufacturing and assembly (Pandza et al, 2003).

Finally, there is a significant shift by original equipment manufacturers (OEM) towards after-market services. At the same time, outsourcing has become commonplace in design and production both within home countries and internationally (McCue, 2006). For example, Rolls-Royce outsources and offshores about 75 percent of its components to its global supply chain and collaborates with other partners for products, services and research & development (Friedman, 2005).

Capacity planning within a supply chain context is a strategic response to the challenges arising from these dependencies (Xu and Beamon, 2007) and requires tools to effectively manage these interactions.

1.2 AIM AND SCOPE OF THE RESEARCH

This deliverable is motivated by our involvement with research on strategic capacity planning (SCP) for the aero-engine sector. The aim is to identify the key issues of SCP in the aerospace industry. The deliverable reviews key concepts related to SCP and also presents insights from two case studies undertaken as part of the work. The case studies focus on the assessment of the impact of SCP on relationship building between supply chain partners.

The deliverable enhances VIVACE partners' understanding of the virtual organisation within which organisations increasingly interact. The objectives of the report are:

1. To describe the aerospace industry, including its characteristics, structure and the changes occurring within it, in the context of strategic capacity planning.
2. To assess the current literature and examine studies on SCP and related areas.
3. To develop a framework for effective coordination in supply chain capacity planning that can assist organisations in assessing their current strategic capacity issues and help to identify the improvements needed in collaboration and relationship building.

The deliverable focuses on capacity planning at the strategic level not at the operational level.

1.3 RESEARCH APPROACH FOR THE CASE STUDIES

The overall approach adopted for this research was qualitative and inductive. In-depth, semi-structured interviews were used along with analysis of secondary data. The research was designed to allow information gathering for the purpose of interpreting decision-making relevant for capacity planning within settings where uncertainty is inherent.

A purpose sampling approach (Glaser and Strauss, 1967) allowed the researchers to draw samples from key organisations and senior management groups that are involved in some way with the issues of SCP. The researchers have conducted two in-depth case studies. Rolls-Royce and VAC were selected for this study of SCP because they are two major participants in the VIVACE project, and also because of the risk-revenue sharing partnership between them.

A total of 10 interviews were undertaken with senior managers working for the companies. Although a relatively small sample, the interviews can be considered to be significant as they include senior managers of relevant departments who were able to comment in detail on industry trends and the strategic decisions of the companies. The research used semi-structured interviews with open-ended questions, allowing respondents to reveal their views and perceptions of SCP. Each interview lasted for one to two hours. The interview protocol was developed in the light of the review of literature on SCP and was used to collect detailed information about interviewees' perception on SCP processes, manufacturing capabilities and management systems. The profile of participants in the case studies is presented in *Appendix I*.

The data were analysed manually due to the manageable size of the interviews. The coding was based on transcripts and field notes. Transcribing, reading and re-reading the interview data provided the bulk of the information analysed with the support by an extensive literature review.

1.4 LAYOUT OF REPORT

In the first chapter of the report the background to the aerospace industry has outlined and the research area and aim and scope of the research have been defined.

Chapter two provides an overview of current theories and views on capacity planning. It critically reviews the findings of various authors in relation to capacity planning issues. It first presents the meaning of capacity, its characteristics and classification. Secondly, it provides the definition and scope of strategic capacity planning. It highlights previous research on strategic capacity planning within the context of an individual enterprise and from an extended enterprise perspective. Finally, a theoretical framework is developed for strategic capacity planning.

Chapter three originally described two case studies, detailing the results of semi-structured interviews at Rolls-Royce (OEM) and VAC (first tier supplier). It was identified, however, that commercially sensitive information was contained in the interview transcripts. Thus, much of this content has been moved to an appendix, not included in the public version of the deliverable.

The final chapter concludes the research. The management implications are presented and ideas are highlighted for further study.

2 LITERATURE REVIEW

This chapter presents a review of the key literature underpinning this research. It reflects the focus of the study on the influences on capacity planning at the strategic level.

2.1 DEFINITION AND SCOPE OF SCP

Capacity is a measure of processing abilities and the limitations that stem from the scarcity of various processing resources (van Mieghem, 2003). According to APICS (1995), capacity management is “*the function of planning, establishing, measuring, monitoring, and adjusting levels of capacity so that sufficient capacity is available to permit execution of the manufacturing schedules*” (cited in Ashayeri and Selen, 2005).

Strategic capacity is concerned with both the tangible and intangible resources from individual entities and value chain systems (including suppliers', customers', partners' and competitors' capacity). At the strategic level, intangible resources are as important as tangible resources and supply chain capacity is more important than individual company capacity. The special issues associated with strategic capacity include: a high degree of aggregation, high risks and uncertainties, long time frames, and the requirements for significant levels of investment.

Both Luss (1982) and van Mieghem (2003) believe that strategic capacity planning is concerned with determining the sizes, types and times of capacity expansions and adjustment. Wu et al. (2005) criticise van Mieghem's work by arguing that it is embedded at the tactical level. According to Wu, et al.'s definition (2005: 127),

“At the strategic level, capacity planning involves not only the firm's own capacity investment but also its supply chain partners' investments. The capacity investment of one firm in the supply chain could have enormous impact on the performances of all upstream and downstream firms; thus, strategic interactions between two or more players need to be taken into account”.

In this report, SCP is considered to be primarily concerned with dealing with uncertainties (e.g. supply, technology and demand), the hedging of risks (e.g. operation risks and financial risks), and building up strategic supply chain relationships (e.g. coordination and trust). SCP decision makers need to assess, hedge and share the risks. The plans need to be flexible enough to deal with these uncertainties and risks by taking the entire supply chain into consideration.

2.2 CAPACITY DYNAMICS IN THE AEROSPACE INDUSTRY

In this section, some issues from case experiences from published data are discussed. Capacity planning may be faced with three uncertainties: (i) demand uncertainty, (ii) technology uncertainty, and (iii) supply uncertainty (Karabuk and Wu, 2003; Serel, 2007).

2.2.1 DEMAND UNCERTAINTY

Demand uncertainty occurs due to the often volatile nature of aerospace industry. For example, according to Budiman (2004), Boeing planned to increase its level of production in order to keep pace with the upswing in the industry in 1995. Over the past two years, its production level has been increased dramatically with production increasing of its 747 aircraft from four to five per month and that of 777 from five to seven per month (Budiman, 2004). Such a plan resulted in a large increase in orders for aircrafts. The Asian financial crisis in

1997, however, led to the significant reduction in demand. Despite initially insisting that the crisis would not have a significant impact on sales, Boeing was forced to cut output substantially (Biddle, 1998).

Another example shows that after the September 11 terror attacks, airlines cancelled or postponed orders in large numbers. Over a few months, Boeing cut its production in half and laid off 35,000 people (Lunsford, 2007). Since this kind of uncertainty could not possibly be anticipated, it was painful for the whole supply chain.

2.2.2 TECHNOLOGY UNCERTAINTY

In the aerospace sector, most firms are committed to invest heavily in research and development. Technological advances, however, can be risky. Technology uncertainty is a fact of life in the aerospace industry due to the needs to continually upgrade technology. The amount of new technology in use and consequently the uncertainty in manufacturing processes introduce high variability in timing of the delivery of orders (Karabuk and Wu, 2003). Thus, outcomes in demand and capacity realisation can lead to long-lasting business consequences that are difficult to recover from.

It is imperative for planners to consider uncertainties explicitly and strategically so as to hedge operational decisions against such uncertainties (Karabuk and Wu, 2003 and van Mieghem, 2006). Lawrence (2006) highlights that the A380 has been repeatedly delayed by technology uncertainties. There have been more modifications required from the digital models than Airbus anticipated and they have taken longer to resolve than managers foresaw.

Ellram and Zsidisin (2002) also mention that technology uncertainty makes supply chain global optimisation difficult. For instance, the production problems at Airbus have been hitting the UK aerospace supply chain hard, with some firms suspending production and others worrying about layoffs (Boxell, 2006). Rolls-Royce has suspended production of engines for A380s for about 12 months (Wall Street Journal, 2006). Half a dozen massive engines for the A380 superjumbo stand idle in one of Roll Royce's final assembly workshops (Collins, 2007). It is clear that the technology problems being experienced by Airbus are amplified across the whole supply chain.

2.2.3 SUPPLY UNCERTAINTY

Supply uncertainty means the shortage of input materials and components used in the production process adversely influence sales of manufacturing firms (Serel, 2007). According to Zsidisin (2003), supply uncertainty is defined as the probability of an incident associated with inbound supply from individual supplier failures or the supply market occurring, where the outcomes result in the inability of the purchasing firm to meet customer demand.

There are two types of supply uncertainty: one is a shortage of raw material and the second is the risk of suppliers' failure. For example, fluctuating demand for aircrafts causes fluctuation in the demand for Titanium. The fluctuation can be so severe that it may cause some suppliers to go out of business during a downturn. A small number of raw material suppliers may sign a long-term contract with OEMs to guarantee a minimum level of supply. In doing so, the suppliers may provide security of supply in the downturn as well as delivering a blow to their competitors. However, this can result in a reduced level of capacity throughout the industry. When the industry experiences an upturn, it is limited by the level of capacity for the raw material - the level of capacity may not recover because some suppliers may have gone out of business and those that remain become very sceptical on the sustainability of the increased level of demand (Budiman, 2004). Supply failure has severe impacts on the OEMs with increased expediting activities and penalties from late deliveries.

Niles (2006) shows an example of supply uncertainty in the supply chain of the aerospace industry. Pratt & Whitney declined the invitation to produce the engine (CFM-56) for the 737-300 but undertook the development of a competing engine (V-2500) in co-operation with Rolls-Royce to compete with GE's CFM-56. But Rolls-Royce was unable to produce its part of the engine and Pratt & Whitney had to take additional responsibility and the V-2500 was delayed for three years (Niles, 2006). Thus supply uncertainty may arise because of a supply chain partner's inability to fulfil its obligations.

2.3 GENERIC ISSUES IN SCP

Chase, et al. (2006) define the objective of SCP as providing an approach for determining the overall capacity level of capacity-intensive resources-facilities, equipment, and overall labour force size – that best supports the company's long-range competitive strategy. Ashayeri and Selen (2005) state that with value creation and customer as a focus, capacity planning must be considered at the strategic level to provide a company with the required operational capabilities. They argue that capacity planning should be considered with the competitive and value-driven dimensions of speed, flexibility and quality, as well as cost.

Unlike other literature and models concentrating on tactical and operational utilisation of resources for enhancing performance, Dekkers (2003) studies the performance of manufacturing and notes that it depends strongly on the portfolio of resources to fulfil its role within the total operations of companies. To implement effective strategic capacity management, methods should be developed to support decision-making on a strategic basis for the utilisation of resources, consisting of process mapping, an evaluation framework and a master plan for technology acquisition, process development and resource management (Dekkers, 2003).

Johansen and Riis (1995) provide a strategic-focused framework that considers a number of company-specific factors (like forecast accuracy, process complexity, etc.) and political and social factors (like interest rates, rate of unemployment, etc.) that are used to guide managers in the capacity planning process (cited in Olhager et al, 2001). Bozarth and McDermott (1998) highlight the importance of the environmental fit and changes in the manufacturing structure.

Capacity planning issues can be seen from different perspectives. Hayes and Wheelwright (1984) use three variables to describe a capacity strategy: the *location* of capacity needed, the *size* of capacity that should be added (or reduced), and the *timing* of capacity changes. In studying the timing issue, three different strategies are employed: leading demand (capacity supply surplus), lagging demand (capacity demand surplus) or track demand (capacity equals to demand) (van Mieghem, 2003; Olhager et al, 2001). Von Lanzener et al. (2002) study the timing issue with consideration of the R&D process. They underline the necessity of integrating R&D requirements in the SCP process. A central part of the sizing problem is scale, where economies as well as diseconomies of scale are weighted against each other (Olhager et al, 2001). The capacity strategy can be expressed as a trade-off between high utilisation and flexibility (Anglani et al, 2005).

Capacity expansion refers to the change of the capacity over time that involves the capital investment in the expectation of future revenue (Van Mieghem, 2003). According to Dixit and Pindyck (1994), most capacity expansion shares three important characteristics in varying degrees: (1) the investment is partially or completely irreversible in that one cannot recover its full cost should one have a change of mind; (2) there is uncertainty over the future rewards from the investment; (3) there is some leeway about the timing or dynamics of the investment (van Mieghem, 2003). In addition to these three, van Mieghem (2003) adds a multidimensionality characteristic where a firm invests in multiple types of resources that

have different financial and operational properties. The capacity portfolio refers to decisions about the types and levels of investment that are interdependent and the firm's productive capabilities depend on the complete vector of capacity levels (van Mieghem, 2003).

Gaimon and Burgess (2003) study size and timing of capacity expansion to bring new products to the market. They describe the trade-off in capacity expansion by operating a small number of large-sized expansions (economies of scale) and a large number of small-sized expansions (flexibility). They suggest that a firm should make several smaller-sized expansions to gain competitive advantage from the reduced lead time.

Miller and Park (2005) study size and timing of capacity expansions in the aerospace industry using a real options method. They suggest that the firm should perform a sensitivity analysis around the key inputs in order to give a comfortable range in which a company can be more confident in their decision. Additionally, they believe that the multi-staged investment scenario facilitates the learning process. By expanding capacity step by step, a company can learn from the previous stage's experience and improve the quality of future decision making.

Most of the above papers apply a mathematical approach to solve capacity planning issues. However, Pandza et al (2003) contend that the real options framework provides an appropriate heuristic approach for managing the process of capability development. They conduct one in-depth longitudinal and retrospective case study of a business unit within the aero-engine division of Rolls-Royce to illustrate that a real options approach can help to manage resources and capabilities. They suggest that the development of resources and capabilities follow a time consuming process by adding and rearranging connections. As a result, managers have to decide which resources and capabilities to commit to ahead of when they might be needed and at a time when their future value is uncertain. Faced with this situation firms will want to invest in resources and capabilities that have value in a range of circumstances.

Pandza et al (2003) argue that a real options approach has three features that offer potential in thinking through the capacity problem. First, real options logic recognises there is value in delaying investments by waiting for market and technological uncertainty to diminish before making a larger commitment. Second, many investments can be undertaken in stages and the real options logic is able to exploit the incremental learning associated with phased investments. Third, options provide a non-linear payoff structure and purchasing an option may enable a firm to take advantage of any upside potential whilst avoiding the downside risk. An option holder has the opportunity to take an action in the future should the situation prove attractive, but not the obligation, should events become unfavourable (Pandza et al, 2003).

2.4 TRADITIONAL AND MODERN VIEWS ON SCP

Since the late 1950s many studies of capacity planning have been conducted at the tactical, operational and strategic levels (e.g. van Mieghem, 2003; Ashayeri and Selen, 2005; Luss, 1982). These are mainly concerned with the determination of the required level of processing resources over time including workforce size, inventory planning, subcontracting, and overtime scheduling (van Mieghem, 2003). However, Handfield and McCormack (2005) show that, although many manufacturers are good at manufacturing planning, they have to work around supply chain difficulties. Thus, capacity planning must be conducted in the context of the supply chain.

When viewed at the level of the supply chain, more and more researchers (e.g. Tomlin, 2000; Erkoc and Wu, 2004; Cachon and Lariviere, 2005) note that the key issue of SCP has changed from capacity expansion to supply chain coordination. SCP in an extended enterprise differs from traditional capacity planning in several ways. Firstly, while traditional

capacity planning considers a deterministic future, SCP considers uncertainty in the future, not just capacity itself (van Mieghem, 2003). Secondly, SCP studies the exchange of information such as demand forecasts within a supply chain and the quality of SCP depends on the dissemination of accurate information between participants in a supply chain (Cachon and Lariviere, 2001). Trust is therefore a key factor in this exchange of information. Thirdly, traditional capacity planning believes that all the expansion risks are taken by the firm itself. Wu et al. (2005:138-139) state:

"Since capacity investments may be capital intensive and demand uncertainty may be high, suppliers may often adopt an exceedingly conservative capacity expansion policy that reduces their downside risk at the expense of upside potential. On the other hand, the OEMs will avoid making firm commitments to the suppliers on their future purchases due to high uncertainty. Consequently, their downstream OEMs may not have adequate supplies to fill the market orders. However, to ensure higher availability, the OEMs might be willing to share risk by sharing partial liability for the capacity as long as it is economically justified. To achieve this, risk sharing mechanisms that create proper economic incentives must be developed"

There is a growing literature about supply chain coordinating contracts that describe mechanisms that align the incentives of supply chain partners via risk/revenue sharing. The availability of the right capacity at the right time may be more critical than the price (Jin and Wu, 2007). Supply contracts such as revenue sharing and capacity reservation can reduce the negative effects of uncertainty on supply chains and enable risk sharing (e.g. Cachon and Lariviere, 2001; Cheng et al, 2002).

2.5 CAPACITY PLANNING MECHANISMS

2.5.1 REVENUE SHARING CONTRACTS

Cachon and Lariviere's (2005) research demonstrates that revenue sharing can be a very attractive contract. An excellent review of supply chain coordination contracts is provided by Cachon (2003). Given a single supplier and buyer, a contract coordinates the supply chain and divides the profits depending on the buyer's purchase quantity and price. The suppliers sell at a price below marginal cost, but they share the buyer's revenue, which should offset the loss on sales. Alternatively, buyers and suppliers can negotiate ways (often referred to as "share-the-pain" agreements) to share the burden of overcapacity in the presence of uncertain demand (Tomlin, 2003).

According to Asanuma (1989), risk-revenue sharing contracts were developed originally in the Japanese Automotive Industry during the 1970s and 1980s. They have since been implemented in supply chain management practices such as cost structure analysis, total cost of ownership and target costing in other industries (Camuffo et al., 2005). The supplier and buyer share some information about business trends, demand forecasts, costs, technological and organisational improvements, and even profit margins (Cachon and Lariviere, 2001).

However, there are limitations to risk and revenue sharing. A first limitation of revenue sharing is the administrative burden it imposes on the firms because the supplier must monitor the buyer's revenues to verify that they are split appropriately (Cachon and Lariviere, 2005). When there is a lack of trust and/or integrated information systems, the monitoring costs may be high (Cachon and Lariviere, 2001). The gains from coordination may not be higher than these costs. Secondly, revenue-sharing contracts may not encourage suppliers to expand their capacity without the consideration of future uncertainty in demand. The essence of such a contract is to push the risk to the suppliers.

2.5.2 CAPACITY OPTION RESERVATION CONTRACTS

According to Wu et al. (2005), capacity option reservation contracts are an increasingly popular way to model the allocation of risks across suppliers and buyers in high-tech supply chains. Such contracts regard capacity as an option to be exercised in the future to produce needed goods. Research on capacity option reservation contracts can be categorised into two groups based on how they motivate the buyer's incentives for reserving capacity (Wu et al., 2005). The motivations may focus on reducing potential cost through early commitments (Serel et al., 2001; Bonser and Wu, 2001), or on ensuring availability during demand upsidings (Cachon and Lariviere 2001; Jin and Wu 2001).

Typically, one OEM and one supplier interacts with each other in two phases (Jin and Wu 2001, 2007; Wu et al., 2005; Spinler, 2003; Jaillet et al, 2004). In the first phase, both parties negotiate a reservation fee, an execution fee, and a reservation quantity. At this stage, the demand is unknown and is usually represented in probabilistic terms. While the reservation fee is immediately payable, the exercise fee is due when the option is exercised (i.e. after demand materialises). Based on the reservation fee, the OEM chooses a reservation quantity, which is compatible with the supplier's capacity. In the second phase, the OEM decides on whether or not to exercise the option depending on the market situation. By appropriately choosing the contract parameters, both parties can improve their expected profit.

Capacity reservation contracts are applications of call option models since each reserved capacity gives the OEM the right but not obligation to purchase capacity in the future (Black and Scholes, 1999). Capacity reservation contracts can reduce an OEM's purchase costs and delivery risks whilst also increasing the supplier's utilisation of installed capacity (Serel, 2007). In fact, it provides a risk-sharing mechanism that encourages suppliers to expand their capacity more by giving them some assurances (Barnes-Schuster, 2002).

2.5.3 CAPACITY OUTSOURCING

Outsourcing is an alternative to vertical integration. In practice, it is a type of make-or-buy decision involving a switch from internal production to external procurement (Tsai and Lai, 2007). A key motivation for outsourcing is to achieve an immediate reduction in the production costs (Gray, et al., 2006). Manufacturers can benefit from the reduction of capital investment and may lower costs by outsourcing non-core activities. However, there are also risks that may arise from outsourcing such as possible loss of control over suppliers (Wang, et al., 2007).

Kouvelis and Milner (2002) analyse the impact of supply/demand uncertainty on capacity and outsourcing decisions. They conclude that capacity reservation applies in the presence of supply uncertainty. Wu et al. (2005) believe that OEMs may have incentives to make reserve capacity with their suppliers to ensure reliable and continuous supply. In contrast, demand uncertainty encourages outsourcing (Kouvelis and Milner, 2002). For OEMs, rather than focusing on physical expansion of manufacturing capacity with significant capital investment and huge investment risks, they may have incentives to expand their capacity for higher revenue from outsourcing because of the high demand volatility (Jin and Wu 2001, 2007).

2.6 A THEORETICAL FRAMEWORK FOR SCP

In today's business environments, organisations are faced with more dynamic and complex business relationships and processes rather than traditional static and simple ones. In order to provide more value to customers, organisations' most important SCP strategy is concerned with integration and collaboration. Organisations may not only need to collaborate with their suppliers and business partners, but often with customers and sometimes with their competitors as well.

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Organisations require an SCP strategy to be not only flexible but also holistic. Appendix II shows how SCP has evolved from focusing on an individual company's physical capacity expansion problems (i.e. time, size, location) to involving all companies in the supply chain by considering factors such as soft expansion (i.e. outsourcing), risk allocation, revenue sharing, information sharing and relationship building.

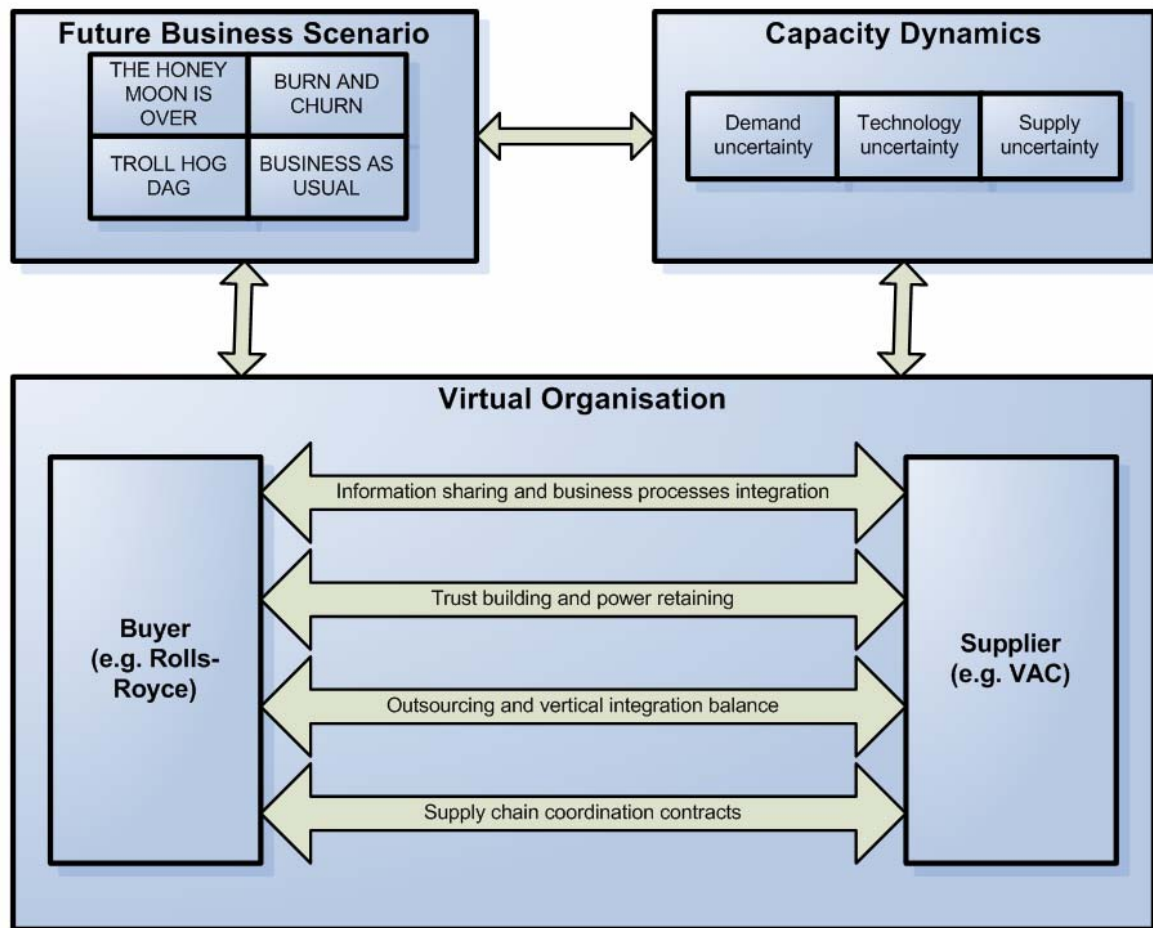


Figure 2-1 A framework for SCP in the aerospace sector

This theoretical framework shown in Figure 2.1 has been developed based on the existing literature review and the characteristics of SCP in the aerospace industry. The objective of the virtual organisation is to develop an integrated network to synchronise the supply chain and facilitate coordination. The framework therefore incorporates four major issues to understand future business scenarios and capacity dynamics and contribute to the promotion of flexible, responsive and lean supply chain by coordinated SCP: (1) Sharing information and integrating business processes; (2) Building trust and retaining power; (3) Balancing outsourcing and vertical integration; (4) Establishing supply chain contracts.

Information systems are vital to the coordination of the supply chain activities and to facilitate knowledge transfer within companies and between supply chain partners. Building trust with, and retaining power over suppliers can enhance the control, coordination and long-term relationships. Balancing outsourcing and vertical integration can manage the supply and

demand uncertainty to optimise the utilisation of resources. Supply chain contracts enable companies to achieve successful risk and revenue sharing and improve supply chain performance.

3 CASE STUDIES (IN RESTRICTED APPENDIX III)

This chapter introduces two cases: Rolls-Royce, a famous aero-engine OEM and Volvo Aero Corporation (VAC), a major first tier supplier. Rolls-Royce Plc is a leading engine manufacturing company serving the global civil aerospace, defence aerospace, marine and energy markets. Rolls-Royce operates in 50 countries (Rolls-Royce Annual Report, 2006) with an extensive customer base of 500 airlines and 4,000 corporate and utility operators (Datamonitor, 2006). Its markets are split evenly between the Americas, Asia and Europe (Rolls-Royce Annual Report, 2006). Volvo Aero is a wholly owned subsidiary of the Volvo Group. Volvo Aero produces components for aircraft and rocket engines as well as providing other services such as leasing to the aerospace industry (Volvo Annual report, 2006). The findings from interviews in these two companies are presented below. For the confidential reason, the main findings from primary research have been moved to a separate document.

4 CONCLUSION

In this deliverable, SCP has been studied with the aim of developing a framework for a coordinated SCP in an extended enterprise in the aerospace sector. The main objectives were to understand the characteristics, structure and the changes occurring within the aerospace sector in the context of SCP, identify key SCP issues and highlight the importance of supply chain coordination.

4.1 SUMMARY OF LITERATURE

Strategic capacity is concerned with both the tangible and intangible resources from individual entities and value chain systems (including suppliers', customers', partners' and competitors' capacity). At the strategic level, intangible resources are as important as tangible resources and supply chain capacity is more important than individual company capacity.

SCP is concerned primarily with how to deal with: uncertainties, in particular supply, technology, demand uncertainties; the hedging of risks, including both operational and financial risks; and building up of strategic relationships (e.g. coordination and trust).

SCP in the extended enterprise is more dynamic than traditional capacity planning because of the increased uncertainty and requirements of information exchange within a supply chain. Uncertainties were shown to have significant impacts on strategic capacity planning. The capacity uncertainty problems of one company can amplify in the whole supply chain. The uncertainty in demand due to the volatile nature of the industry undermines the efficiency of capacity planning. These uncertainty issues may forge closer relationships between supply chain participants. The effectiveness of SCP also depends on the dissemination of accurate information in the supply chain. In the aerospace industry, the availability of the right capacity at the right time may be more critical than the price. Establishing supply chain contracts, employing outsourcing, building trust, and transparency in information are key issues in improving the effectiveness of SCP and facilitating coordination in the supply chain.

There is a growing literature about supply chain coordinating contracts describing mechanisms that align the incentives of supply chain partners via risk-revenue sharing. Supply contracts such as revenue sharing contracts and capacity reservation have the potential to reduce the negative effects of uncertainty on supply chains and enable risk sharing.

Revenue sharing contracts coordinate the supply chain by dividing the profits between partners where the suppliers initially sell at a price below marginal cost and then share the OEM's future revenues, which should share OEMs initial risks and offset the loss on sales (Cachon and Lariviere, 2005). In contrast to the traditional approaches in capacity investment that assume all the investment risks are absorbed by the firm that owns the capacity, capacity reservation contracts provide a risk-sharing mechanism that encourages suppliers to expand their capacity more by giving them some assurances (Jin and Wu, 2007). Without the commitment from OEMs, suppliers may not risk capacity expansion and consequently downstream OEMs may not have adequate supplies to fill the market orders.

Outsourcing can be seen as an alternative to the physical expansion of capacity. A key motivation for outsourcing is to achieve production cost reduction, reduce financial risk, and enable companies to concentrate on value added activities. Outsourcing becomes more attractive when uncertainty in demand increases but may result in under-investment in the long-term.

SCP decision makers need to assess, hedge and share risks by integrating information systems and building trust with supply chain partners. Organisations sharing a long-term relationship need to align their information systems with one another. Building trust can help to offset uncertainty and risks.

In order to achieve competitive advantage, SCP strategies, therefore, should include the establishment of stable partnerships, outsourcing for efficient manufacture, evolution of the supply chain with risk-revenue sharing contracts, information acquisition and sharing and trust-building across virtual supply networks by linking all members of a supply chain.

4.2 SUMMARY OF CASE STUDY FINDINGS

The findings of the case studies highlight the increased awareness of the importance of contracts and relationship building in the supply chain and the need to design more effective capacity planning strategies and to build up closer trading relationships.

The aerospace industry has undergone a transformation with the airlines viewing low cost not technology as the primary factor in purchasing aircraft. It is a challenge for capacity planning in a supply chain to keep the production costs low, while maintaining responsiveness to adapt to a dynamic environment. Rolls-Royce has focused on its strategy to simplify the supply chain and outsource non-core components to low cost suppliers. VAC adopted a lean production principle with the aim to maximise utilisation and increase productivity. By optimising operational level activities, companies can achieve lean production. However, lean thinking should be carried out at both operational and strategic levels. At the strategic level, companies have to rethink how to position themselves in a supply chain. Rolls-Royce must ensure that it controls critical resources in the supply chain because it is no longer just a company competing with other companies, but its supply chain is competing against its competitors' supply chain. VAC must think whether or not to reinforce coordination with Rolls-Royce to facilitate their one-to-one relationship. Strong relationships between upstream and downstream partners will lead to effective SCP and improved supply chain performance.

Coordination, however, is hard to achieve in Europe because of the opportunistic rather than deferential relationship between OEMs and suppliers. VAC's strategy of having a portfolio of customers may limit its ability to develop improved supply chain relationships. Rolls-Royce has not gained dominant power and VAC can choose who it supplies. The problem may be the lack of trust and incentives to create a real lean partnership. Supply chain contracts, however, can facilitate the coordination in the supply chain.

It has been found in the case study that Rolls-Royce requires its suppliers to mutually support it but avoided making firm commitments on volume due to high uncertainty. On the other hand, VAC hesitates to be too close to any one OEM or expand capacity because the investment cost will need to be absorbed by itself.

For Rolls-Royce, supply uncertainty is high. Although it has the revenue sharing contracts with supply chain partners in which each partner to share a portion of the financial risk, it might not give suppliers an incentive to increase capacity. Since greater supply uncertainty encourages capacity reservation, Rolls-Royce may have incentives to make firm commitments to VAC to ensure reliable and continuous supply. In doing so, risks are absorbed by the supply chain partners where OEMs are concerned not only with short-term profit maximisation but also with building and maintaining long-term relationships with reliable and capable suppliers.

Due to the OEMs' aggressive expansion and the high demand uncertainty, for VAC, rather than focusing on physical expansion of manufacturing capacity with significant capital

investment and huge investment risks, it may have incentives to expand its capacity for higher revenue from outsourcing.

The objective of the virtual organisation is to develop an integrated network with supply chain partners to promote flexibility, responsiveness and leanness (Sinha, et al., 2004). The challenge of SCP is to plan and control the capacity between the OEM and its upstream suppliers and downstream customers in order to maximise the value of the entire supply chain.

4.3 CONTRIBUTIONS AND LIMITATIONS

This deliverable has some strategic implications for organisations in the aerospace sector. An SCP framework has been proposed in section 2.6 to consider SCP decisions. It emphasises: the improvement of existing SCP practices by collaborating supply chain partners; better understanding of the importance of utilising outside resources; the importance of tradeoffs between vertical integration and outsourcing; the establishment of revenue sharing and capacity reservations contracts to optimally allocate risk and revenue between supply chain partners; enhancing the awareness of risk sharing by balancing the trust and power within the supply chain to overcome information asymmetry and offset uncertainty and risks. Risk sharing is suggested to be included as an SCP cornerstone in the design and management of supply chain networks.

However, it should be noted that only a small and specific sample of respondents were interviewed for this research. Many key issues such as timing, sizing, and location for capacity planning were not explored deeply due to the interviewees' limited responsibilities and experience in these areas. In addition, this research was limited to the vertical relationship between OEM and its first-tier supplier. The feasibility of reservation contract and outsourcing can be investigated in the whole supply chain including second-tier suppliers.

4.4 AREAS FOR FUTURE RESEARCH

This deliverable has been primarily based on a qualitative case study approach combined with analysing the literature. This study is being linked with the value chain modelling and simulation work in VIVACE. Simulation of future business scenarios is being used to further understand SCP issues in the aerospace sector.

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APPENDIX I CASE STUDY PARTICIPANT PROFILE

Case Study Participants	Department
Rolls-Royce	Strategy development
Rolls-Royce	Business development
Rolls-Royce	Supply chain development
Volvo Aero Corporation	Strategy
Volvo Aero Corporation	Purchasing
Volvo Aero Corporation	Logistics & operational planning
Volvo Aero Corporation	Business development
Volvo Aero Corporation	Logistics
Volvo Aero Corporation	Production
Volvo Aero Corporation	Business development

APPENDIX II KEY FINDINGS IN EMPIRICAL PAPERS

Author(s)	Title	Method	Industry	Research Area(s)	Key Contribution(s)
Manne (1967)	<i>Investments for Capacity Expansion: Size, Location and Time-Phasing</i>	Case study	Heavy process industries -Aluminium	Capacity investment	The fundamental trade-off between the economies-of-scale savings of large expansion sizes versus the opportunity cost of installing capacity before it is needed.
Luss (1982)	<i>Operations research and capacity expansion problems: a survey</i>	Literature survey	Heavy process industries, communication networks, electrical power services and water resource systems	Capacity investment	This paper unifies the existing literature on capacity expansion problems, emphasising modelling approaches, algorithmic solutions, and relevant applications.
Rajagopalan (1998)	<i>Capacity expansion and equipment replacement: A unified approach</i>	Empirical Computational study	N/A	Capacity investment and (equipment) replacement	This is the first paper that presents a unified approach to capacity expansion and equipment replacement in a deterministic setting.
Cachon & Lariviere (1999)	<i>Capacity choice and allocation: Strategic behaviour and supply chain contracting.</i>	Empirical	N/A	Capacity investment and allocation	This paper considers a supply chain that the supplier's capacity investment and allocation decisions to several downstream retailers that have private information.
Kouvelis & Milner (2002)	<i>Supply chain capacity and outsourcing decisions: The</i>	Empirical	N/A	Capacity investment V.s. Capacity	This paper considers supply chains and analyses the impact of supply/demand uncertainty on

	<i>dynamic interplay of demand and supply uncertainty</i>			outsourcing	capacity and outsourcing decisions. It concludes that greater supply uncertainty encourages vertical integration, because the OEMs have incentives to make investments in their suppliers to ensure reliable and continuous supply. In contrast, outsourcing becomes more attractive as uncertainty in demand increases.
van Mieghem (2003)	<i>Capacity management, investment, and hedging: Review and recent developments</i>	Literature survey	N/A	Capacity investments	This paper is a comprehensive survey of the OM literature on the size, type, and timing of capacity investments. It presents different methods / models of risk management in the capacity investment.
Tomlin (2003)	<i>Capacity investments in supply chains: Sharing the gain rather than sharing the pain</i>	Empirical	N/A	Capacity reservation	This paper considers capacity reservation contracts in which the parties share the benefits of high demand rather than the pain of low demand.
Seshadri & Mishra (2004)	<i>Relationship Marketing and Contract Theory</i>	Case study	Software service	Capacity reservation	This paper illustrates the convergence between contract theory and relationship marketing management with examples from procurement in the supply chain, and capacity reservation contracts.

Wu, Erkoc & Karabuk (2005)	<i>Managing Capacity in the High-Tech Industry: A Review of Literature</i>	Literature survey	High-tech	Capacity planning and management	This paper reviews emerging models in operations research, game theory, and economics that address strategic, tactical and operational decision models for high-tech capacity management.
Serel (2007)	<i>Capacity reservation under supply uncertainty</i>	Empirical Computational study	None	Capacity reservation	The paper concludes that uncertain supply markets lead to increased share of inputs purchased in advance via long-term contracts. Capacity reservation contracts are shown to increase capacity utilisation of the supplier compared to the traditional unit-price based supply contracts.
Jin & Wu (2007)	<i>Capacity reservation contracts for high-tech manufacturing</i>	Empirical	High-tech	Capacity reservation	This paper compares the similarities and differences between the capacity reservation contracts and other well-know supply contracts such as buy-back.

APPENDIX III CASE STUDIES - RESTRICTED

For the confidential reason, the main findings from primary research have been moved to a separate document.