The University of Nottingham

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Manufacturing Technology Selection: A Supply Chain Perspective

by

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Dedicated to my parents

Farooq Ahmad

and

Shahnaz Zainab

Abstract

This thesis describes a technology selection framework for manufacturing technology selection. Technology selection has been identified as a major area of decision making in a company's manufacturing strategy and is highlighted as a manufacturing objective that can provide competitive advantage to a company. The research identifies the emergence of global supply chains as a major phenomenon that has revolutionised the global business environment. Considering the presence of global supply chains and their ever increasing importance the research has proposed a process for manufacturing technology selection keeping in view the supply chain perspective. The technology selection framework introduces the concept of risk evaluation of available technology alternatives for strategic technology selection. The risk associated with technology alternatives is evaluated in the shape of opportunities and threats. The decision making environment for technology selection is divided in a way to consider intra as well as inter-organisational factors. The classification of the decision making environment, inclusion of risk calculations and consideration of a supply chain perspective enables the developed technology selection framework to thoroughly evaluate a technology alternative before its strategic selection.

The research presented in this thesis is composed of two main sections. The first section deals with the development of the technology selection framework, whereas the second section describes the application of the developed framework in an aerospace manufacturing company in detail. The application of the framework in industry helped in understanding the issues surrounding the technology selection process and provided an insight into how the existing technology selection processes can be improved and why it is necessary to address the supply chain factors functionally as well as holistically in manufacturing technology selection.

The major contribution of this research is a technology selection framework integrating manufacturing and the supply chain. Academically the research establishes a link between manufacturing technology selection and the supply chain and emphasises the importance of alignment between manufacturing and supply chain objectives.

Keywords: Manufacturing Strategy, Technology Selection, Supply Chain, Decision Making, Action Research (AR), Analytical Hierarchy Process (AHP), Strategic Assessment Model (SAM), Risk Calculations, Opportunities and Threats.

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Chapter 1

Introduction

1.1 Introduction

Manufacturing is at the forefront of technological advancements and has played a crucial role in the development of societies. Recognition of manufacturing as a source of competitive advantage has resulted in the success and development of manufacturing strategy as a relevant field in operations management. Recent developments in the field of information technology and ease of global transportation and logistics have given birth to global supply chains. The introduction of global supply chains have had a strong impact on the manufacturing sector, which has resulted in manufacturing being considered within a highly competitive global environment. Today in the manufacturing industry it is not enough simply to optimise the internal structures and infrastructures based upon business strategy. Realising the change in the global business environment companies in the manufacturing industry are collaborating with the suppliers and customers in their unique supply chains to achieve the seamless integration of manufacturing and supply chain. One of the key enablers of world class manufacturing is 'technology' that stands above all other pre-requisites for high class manufacturing. This research identifies selection of manufacturing technology as an integral part of manufacturing strategy and presents a technology selection framework for manufacturing technology selection considering the supply chain perspective.

The growing trend towards outsourcing and increasing product complexity has caused a shift in the source of competitive advantage from a single company to a group or chain of companies (Rice and Hoppe, 2001). The literature acknowledges the importance of supply chain management and suggests integration of all key business processes from end users to the original suppliers (Burgess, 1998) for the total optimisation of the supply chain. However supply chain integration is strictly dependent on co-ordination mechanisms for streamlining and interconnecting business processes both within and outside the company boundaries (Cagliano et al., 2006).

A greater level of communications among manufacturing decision makers and external sources of information, and knowledge related to capabilities, technologies and strategies affecting the manufacturing plant, leads to better manufacturing improvement programmes (Rosenzweig et al., 2003). A higher level of inter-organisational communication enables the manufacturing plant organisation to anticipate and more fully respond to changes in a customer's specific needs, new markets and technological opportunities. Hence strategic manufacturing integration with the supply chain involves knowledge dissemination and sharing activities that create new knowledge, which in turn improves organisational capabilities (Swink et al., 2007).

By considering the advantages of information sharing in the supply chain for improving manufacturing capability of a company and the dependence of a supply chain on a co-ordination mechanism for achieving a greater level of integration, this research presents a technology selection framework for manufacturing technology integrating manufacturing and the supply chain in a single decision making loop. The developed technology selection framework improves the manufacturing capability of a company by helping it select the desired manufacturing technology. At the same time the framework acts as a co-ordinating mechanism between manufacturing and the supply chain providing the initial guidelines towards supply chain integration by considering inter-organisational factors in a company's technology selection decision making process. The technology selection framework divides the decision making environment into manufacturing, supply chain and general environments. The opportunities and threats associated with technology alternatives in the three decision making environments are listed. The manufacturing environment deals with opportunities and threats associated with technology alternatives from an intra-organisational perspective whereas the supply chain environment consists of inter-organisational opportunities and threats. Risk associated with each technology alternative is determined in the shape of opportunities and threats associated with the technology alternative in the three decision making environments.

The division of the decision making environment into three distinct environments, the determination of opportunities and threats in the three defined environments and a risk evaluation of the opportunities and threats in the three environments provides a comprehensive analysis for technology selection decision making. The technology selection framework is operationalised in an aerospace manufacturer in a detailed case study to evaluate its practical applicability in the industry.

1.2 Research Objectives

The main objectives of this research are:

1. To develop a decision making framework for manufacturing technology selection incorporating manufacturing and supply chain considerations in a single decision making loop.

2. To develop a link between the content and process side of manufacturing strategy using a technology selection framework as an example.

3. To demonstrate that manufacturing technologies simultaneously provide different opportunities and threats that contribute towards their evaluation.

4. To demonstrate that the risk associated with the manufacturing technology plays a significant role in the selection of a strategic technology alternative.

5. To test and refine the technology selection framework using practical company case studies.

1.3 Research Questions

The main questions that are addressed in this research are:

- How can the supply chain be included in the manufacturing technology selection process?

- How can the process of technology selection in the context of manufacturing strategy be operationalised?

- Why is it important to address the risk associated with opportunities and threats provided by a technology in choosing a strategic technology alternative?

1.4 Scope of Research

This research aims to develop a decision making framework for manufacturing technology selection and has the following scope:

- The research is mainly focused on a decision making framework for manufacturing technology selection considering intra as well as inter-organisational factors.

- The method of manufacturing technology evaluation is adapted from current multiple criteria decision making techniques.

- The technology selection process is targeted towards linking manufacturing strategy content and process while evaluating the risk associated with a selected technology.

The major contributions from this research are:-

1. A decision making framework for industrial managers to select a manufacturing technology that satisfies their supply chain objectives as well

as justifying the technology strategically in terms of opportunities and threats that are associated with it.

2. Academically the research will establish a link between manufacturing technology selection and the supply chain and will address the importance of the issue of how manufacturing technology selection decisions should be made in accordance with the needs of a supply chain.

1.5 Research Process

This research consisted of two stages that included development of a technology selection framework and the operationalisation of the technology selection framework in industry. The development of the technology selection framework was carried out by reviewing the literature, engaging with a 'University Technology Centre' and involving company managers. The initial technology selection framework was then implemented in a pilot case study to determine its functionality. The initial framework was also presented to academics in the shape of an academic paper. The feedback from the academics and the observations from the pilot case study helped to refine the technology selection framework. The refined framework was then implemented in an aerospace manufacturer in a detailed case study. Seven different engine components belonging to different engines were identified for the technology selection process. There were nine different technologies available for the selection purpose. Nine different technology managers and supply chain managers from the business unit's to which the different selected engine components belonged were engaged in the implementation of the technology selection framework.

1.6 Thesis Structure

This thesis is divided into seven chapters as shown in figure 1.1.

- Chapter 1 describes the research objectives, research questions and scope of this research.

- Chapter 2 documents the literature on manufacturing strategy, supply chain and technology selection. Technology selection frameworks available in the literature are explained in detail. The chapter then highlights the gaps in the existing literature.

- Chapter 3 provides the research methodology. The chapter justifies the methodology adopted for this research and explains the research design.

- Chapter 4 presents the technology selection framework in detail explaining all the steps involved in the framework. The chapter provides the detailed working of the techniques employed in the technology selection framework. A pilot case study is then presented to test the initial application of the framework in industry.

- Chapter 5 introduces the detailed case study. It explains the reason behind the interest of aerospace manufacturers in this research. The operations of an aerospace manufacturer are then explained. Next the aero engine components for technology selection are identified and finally the application of the technology selection framework is explained in detail.

- Chapter 6 provides the detailed case study analysis. The chapter documents the calculations of the technology selection framework and explains the significance of the results. The chapter documents the functional integration of the technology selection framework with the existing technology selection decision making process at the aerospace manufacturer. The mutual intersection of the aerospace manufacturer's operational excellence model and the technology selection framework is also provided.

- Chapter 7 discusses the research contributions in terms of academic as well as industrial contributions. The chapter describes the wider application of this research, research limitations and directions for future research. Finally the chapter concludes by summarising the conclusions drawn from this research.

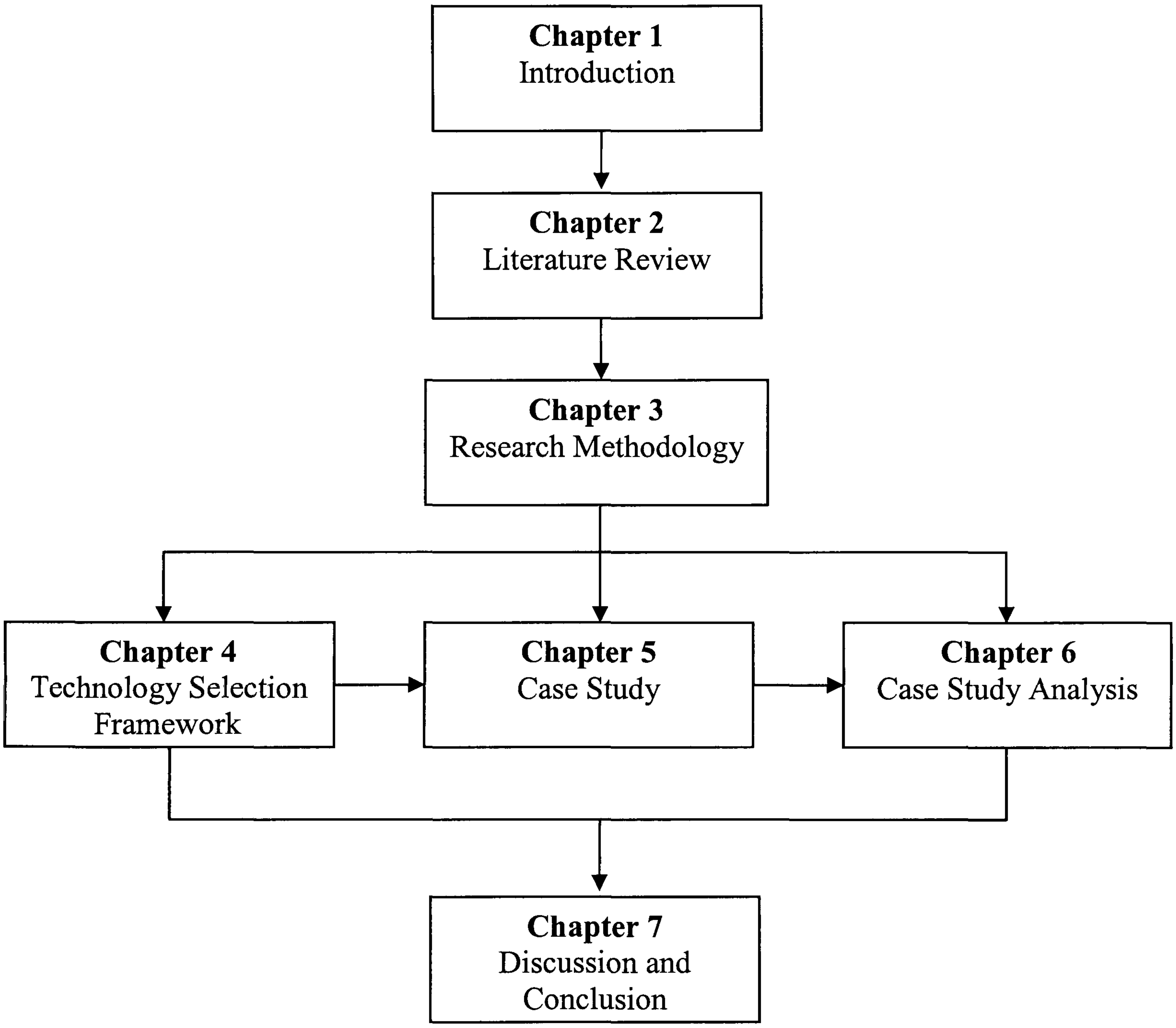

Figure 1.1: Thesis Structure

Chapter 2

Literature Review

2.1 Introduction

This chapter provides a literature review on the three fields of study namely manufacturing, supply chain and technology selection associated with this research. The chapter starts with the literature on manufacturing strategy and then discusses the emergence of supply chain strategies. Strategic use of technology is then documented and a detailed review of the existing technology selection tools, frameworks and methodologies is presented. The gaps in the existing literature are then identified for the direction of this research.

2.2 Research Context

This research combines three areas of study including technology management, supply chain management and manufacturing strategy as shown in figure 2.1.

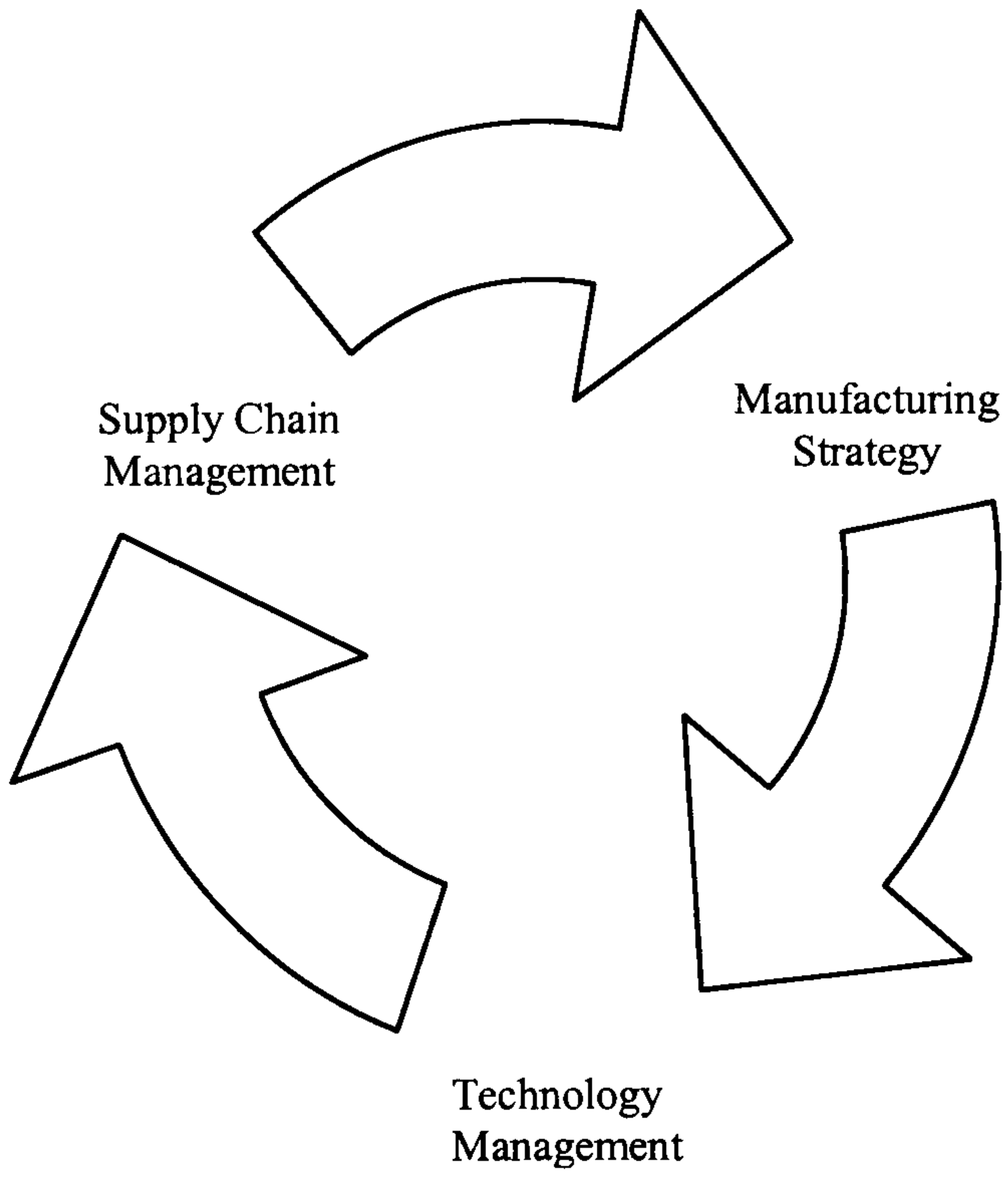

Figure 2.1: Continuous Relation between Three Fields

2.3 Background to Manufacturing Strategy Literature

Initial work of Skinner (1969) is attributed among the very first in the field of manufacturing strategy. Different researchers have used different terms to describe the broad subject of manufacturing strategy. Skinner (1978) used the concept of manufacturing task while Richardson et al. (1985) used the concept of manufacturing mission. Despite development of this field of research some of the definitions are still conflicting (Anderson et al., 1989). Ignoring these theoretical differences most of the researchers generally agree manufacturing strategy is a long range plan and is the future manufacturing vision of a manufacturing setup (Schroeder et al., 1986; Hayes and Pisano, 1994; Hayes and Upton, 1998; Porter, 1996). Hill (1995) further described strategy as achieving a unique positioning of a company in the market.

Traditionally manufacturing strategy has been considered from two perspectives: content and process (Leong et al., 1990; Minor et al., 1994; Swink and Way, 1995; Dangayach and Deshmukh, 2001). According to Slack et al. (2001) the content of manufacturing strategy contains the specific decisions that decide the manufacturing direction of the company, while the process of manufacturing strategy consists of methods and framework that are used by a manager to make the specific content decision.

2.3.1 Content of Manufacturing Strategy

The content of manufacturing strategy has evolved over the years from industrial and factory management in the 1950's to operations management in the 1960's and 70's. Operational strategy became an important field of management study in the 1980's and now the importance of manufacturing and operations management is recognised among researchers and this has resulted in greater integrated research with other fields of study (Gresswell et al., 1998). One of the most interesting and comprehensive papers describing the existing paradigms in the content of manufacturing strategy was documented by Voss (1995) and described the following existing approaches:

a. Competing Through Manufacturing

The concept that manufacturing strategy is a part of overall business strategy is supported by Hayes and Wheelwright (1984) and is indicated in their manufacturing strategy framework. The main task is to describe the overall corporate/business objective of an organisation. Return on investment, growth and profit features in the business objective. In order to achieve the business objectives several manufacturing objectives have been defined which include cost, quality and delivery and to fulfil these manufacturing objectives various structural (capacity, facility, technology, vertical integration) and infrastructural decisions (workforce, quality, production planning, and organisation) have to be made.

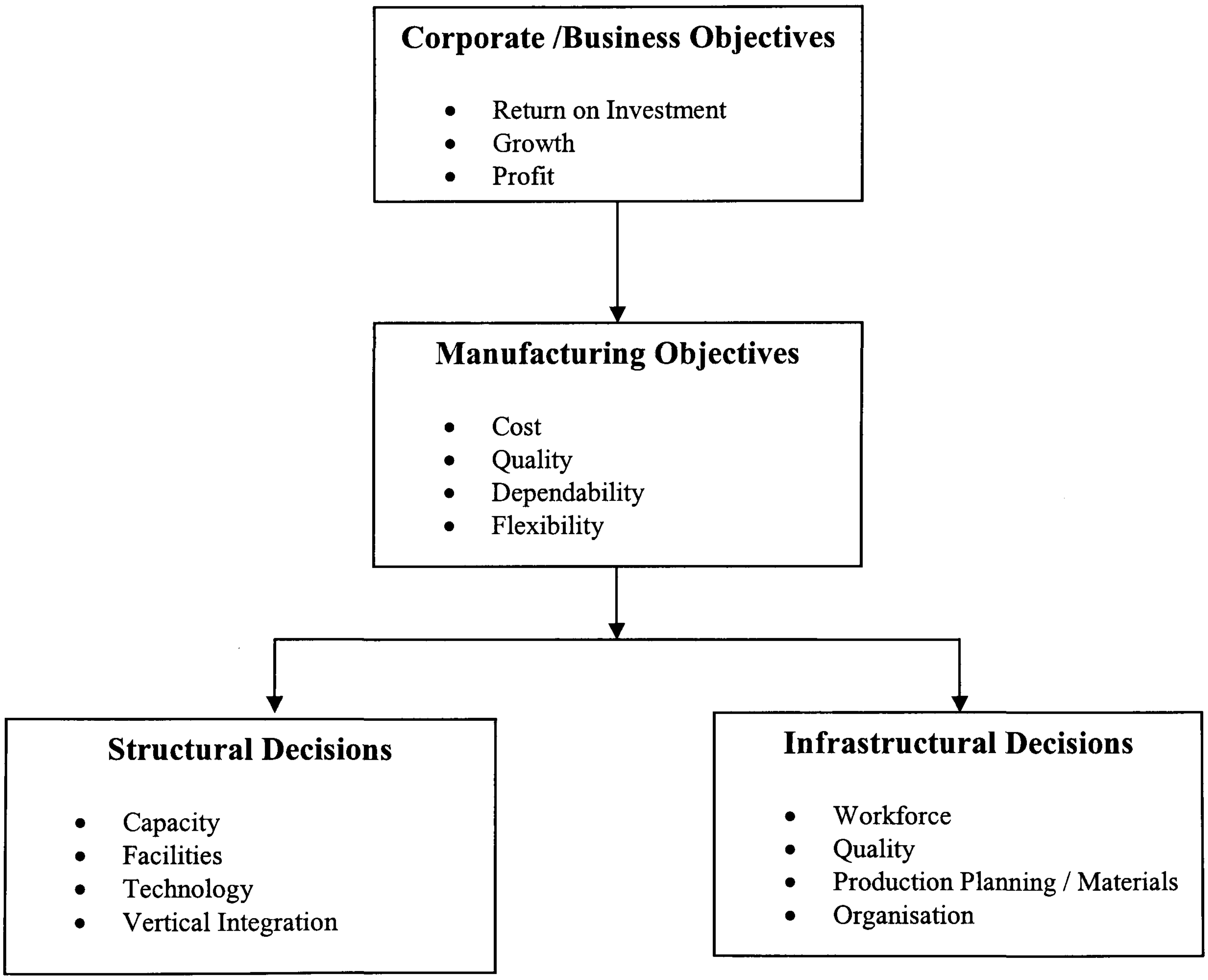

Figure 2.2: Hayes and Wheelwright Manufacturing Strategy Framework (1984)

Lynch (1997) stressed that the success of a company depends on its ability to appropriately define its corporate and operational objectives. Similarly it is important to define the manufacturing objectives of a company that should be consistent with the overall business/corporate objectives. In the manufacturing strategy literature different terms have been used by various authors like competitive variables (Marucheck et al. 1990), competitive criteria (Platts and Gregory, 1990) and order winning criteria (Hill, 1989).

Hill (1985, 1989) introduced terms like 'qualifying criteria' and 'order winning criteria' as integral constituents of a manufacturing strategy. Qualifying criteria is defined as the minimum characteristics of a product which customers expect to be present in the product. Order winning criteria are unique characteristics of a product that make it more attractive to the customers. Over the years order winning criteria have been transformed into order qualifying criteria as the customer have become more demanding and there is pressure of global competition (Corbett and Van Wassenhove, 1993). The big contribution of Hill is that he has included the customer in the loop of manufacturing. He emphasised on the need of understanding the fact that to run a successful manufacturing company one has to bring in the customers with the product design team. The final decision rests with the customer whether to buy a certain product or look for any other alternatives. So it is important to involve the customer from the first stage of product conceptualisation.

In the manufacturing strategy literature the choice of competitive priorities and international comparisons of different countries have been widely studied (DeMeyer, 1992). Such approaches are consistent with the business strategy concept of Porter (1980). Porter's generic strategies like cost leadership, focus and differentiation can be considered as business priorities directing manufacturing choice and management. Different attempts have been made to define generic manufacturing strategies. Stobaugh and Telesio (1983) based their manufacturing strategy on cost, technology and market driven strategies. Similarly Miller and Roth (1994) developed a taxonomy of manufacturing strategies.

It is an established fact that alignment of manufacturing capability with key success factors will maximise the competitiveness of a firm. Manufacturing capability can include anything from manufacturing technology to achieve the desired corporate objectives to the ability to launch new products rapidly (Voss, 1986). Hayes and Wheelwright (1984) have argued that companies should go beyond looking to align capabilities with the marketplace. Manufacturing should seek to influence the corporate strategies and should develop and exploit manufacturing capability proactively as a competitive weapon. Platts and Gregory (1992) approach also focuses identifying the current manufacturing strategy and to assess what impact this has on the achievement of objectives. There has been extensive work on identification and development of manufacturing capability, for example Slack (1983) and Jaikumar (1986) have examined the area of flexibility in manufacturing and flexible manufacturing systems to increase manufacturing capability.

b. Strategic Choices in Manufacturing Strategy

Skinner (1969) identified plant and equipment, production planning control, labour, staffing, product design, engineering and management as key choice areas in manufacturing strategy. Hayes and Wheelwright (1984) expanded this into structural and infrastructural decisions whereas Hill (1993) highlighted two areas process and infrastructure. Much literature regarding strategic choices in manufacturing strategy is focused on the choice of manufacturing process. Its origins can be traced back to the work of Woodward (1965) but Hayes and Wheelwright (1984) were the first true exponent in manufacturing strategy using their product process matrix. They showed how misalignment between manufacturing objectives and the selected process can lead to poor manufacturing and business performance. They also argued that as markets evolved and changed so did the required process.

The process choice concept has been developed by many authors. Kim and Lee (1993) have developed a taxonomy of process based on technical flexibility and technical complexity. They related new manufacturing technologies to the traditional processes used by Hayes and Wheelwright. Pine et al. (1993) add to this the concept of mass customisation, arguing that process is not only a choice but there is an optimal route from one process to another.

c. Best Practice

Best practice is among the recent terms to surface on the manufacturing strategy literature. The scene of best practice literature is dominated by Japanese industrial experience. The best practice literature includes just in time manufacturing which has evolved into lean production, total quality management and concurrent engineering. Several catalysts like outstanding performance of Japanese manufacturing industry, business process based approaches and bench marking and finally the emergence of international quality awards like 'European Quality Award' and 'Malcolm Baldridge Quality Award' has brought best practice to the centre stage of manufacturing strategy. The concept of best practice is synonymous with the idea of world class manufacturing. This phenomenon was also first highlighted by Hayes and Wheelwright (1984) but it got wider global recognition after the publication of Schonberger's book "World Class Manufacturing" (1986).

	Competing through manufacturing	Strategic choices in manufacturing	Best practice
Key concepts	Order winners Key success factors Capability Generic manufacturing strategies Shared vision	Contingency approaches Internal and external consistency Choice of process Process and infrastructure Focus	World-class manufacturing Benchmarking Process re-engineering TQM Learning from the Japanese Continuous improvement
	Process		
	Measurement		

Figure 2.3: Three Paradigms of Manufacturing Strategy (Voss, 1995)

2.3.2 Process of Manufacturing Strategy Formulation

According to Miller and Hayslip (1989) a process that leads strategy to action is needed for successful strategy operationalisation. Operationalisation of strategy through effective management is critical to strategic planning (Das et al., 1991; Lederer and Sethi, 1998). While manufacturing literature is rich in content of manufacturing strategy, there has been scant literature concerning the process of manufacturing strategy formulation (Menda and Dilts, 1997). This idea that process of manufacturing strategy formalisation is as important as its content is also advocated by Adam and Swamidass (1989) and Anderson et al. (1989).

In business strategy literature, researchers have devoted considerable space to the subject of how formalisation of strategies affects the companies strategic actions and decisions but very few empirical studies have identified the formalisation of manufacturing strategy. As summarised by Leong et al. (1990) 'process research has been relatively neglected conceptually and almost totally neglected empirically'. Acur et al. (2003) mentioned that they could only find three studies regarding content of manufacturing strategy which addressed the formality of action plans specifically. Anderson et al. (1991) compared the degree of formality between manufacturing and business strategies and concluded that manufacturing strategy was less formalised then the business strategy. Similarly Schroeder et al. (1986) studied how manufacturing strategy is defined in practice, identifying the strategies and content elements of manufacturing strategies. Companies with a formalised manufacturing strategy tend to have effective communication among all level of organisation to achieve the desired goals (Tunalv, 1990). All these research contributions lead to the conclusion that a formalised manufacturing strategy is characterised by explicitly expressed objectives, improvement goals and action plans. The relationship between different variables as well as the effect of non formalised manufacturing strategy relative to formalised manufacturing strategy is not clear as it requires more empirical work to clearly understand the impact of formalisation on content, practices and effects of manufacturing strategy.

The most prominent literature is the work of Skinner (1969, 1974, 1985), who advocates a top-down manufacturing strategy generation approach to guide manufacturing managers. Skinner's method of top down hierarchical approach to strategic planning was dominant in industry as reported by the study of Marucheck et al. (1990). Fine and Hax (1985) used a case study based approach to illustrate the application of their manufacturing strategy. The steps involved in the process were similar to that of Skinners earlier work but they also incorporated many ideas from Hayes and Wheelwright work. On the similar pattern Platts and Gregory (1992) take the 'manufacturing audit' approach and suggested a step-by-step model to operationalise earlier strategy frameworks.

2.4 Introduction to Supply Chain Strategy

The traditional perspective of strategy formulation is that every firm is concerned with formulating its own organisational strategies independent of the strategies formulated by other members of the network. This approach supports the view that competitive advantage is sought on an organisation specific basis rather than on the basis of the value chain to which the firm belongs. In this kind of approach the relevant unit of analysis is a firm. However recent research examining networks suggests that networks can be a source of competitive advantage (Dyer, 1996; Dyer and Singh, 1998; Poirier, 1999). This has shifted the focus of competitive advantage from the single organisation to inter-organisational resources. Therefore strategy formulation from an inter-organisational perspective positions the network as the unit of analysis. As the attention is shifted from a single organisation to the entire network so the term 'supply chain' evolved.

A supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers. Supply chains exist in both service and manufacturing organisations, although the complexity of the chain may vary greatly from industry to industry and firm to firm. Supply chain management can be described as a co-ordinated set of techniques to plan and execute all steps in the global network used to acquire raw materials from vendors, transform them into finished goods, and deliver both goods and services to customers. It includes chain-wide information sharing, planning, resource synchronisation and global performance measurements. Researchers have used the phrase 'supply chain strategy' to describe a firm's business and customer performance goals for the supply chain (Johnson et al., 1998; Tydall et al., 1998) or to refer to other operating tactics for the supply chain (Pagh and Cooper, 1998) or features of the design of the supply chain (Cooper et al., 1997; Robinson and Saterrfield, 1998).

Nowadays firms do not compete for the end customers. They compete with each other for position in desirable supply chains (Bradley et al., 1999; Harland et al., 1999; Cox, 1999). They then concentrate on developing the necessary capabilities that will make them valued members of the supply chain (Fine, 1999). Once developed these firm based capabilities become the resources the supply chain draws on in its competitive struggle with other supply chains for loyal end users (Skrabec, 1999). Hence in the network view the competitive success of a firm depends on the competitive success of the supply chain (Poirier, 1999).

Several researchers have developed various frameworks for formulating supply chain strategy. According to Fisher (1997) the design of a supply chain should be in accordance with the characteristics of the products. He concluded that innovative products require responsive supply chains whereas functional products require efficient supply chains. Other researchers like Lummus et al. (1998) view supply chain strategy as an extension of a firm's business strategy and stressed that firms should adopt those supply chain strategies that are likely to improve the supply chain operations which in turn helps the company to attain their business objectives.

The nature of the global business environment has made it necessary for the successful manufacturer to carefully link its internal processes to external suppliers and customers in unique supply chains (Frohlich and Westbrook, 2001). The importance of supply chain integration is an established fact however the knowledge regarding different forms of integrations and their effect on manufacturing performance is relatively weak. The majority of the literature for manufacturing and supply chain integration comes from the process re-engineering literature that advocates the seamless co-ordination of manufacturing processes across the supply chain (Anderson and Katz, 1998). The Supply Chain Operations Reference (SCOR) model shown in figure 2.4 is an example of a management tool that is devised on the principle of supply chain integration by enabling users to address supply chain management practices within and between all concerned parties.

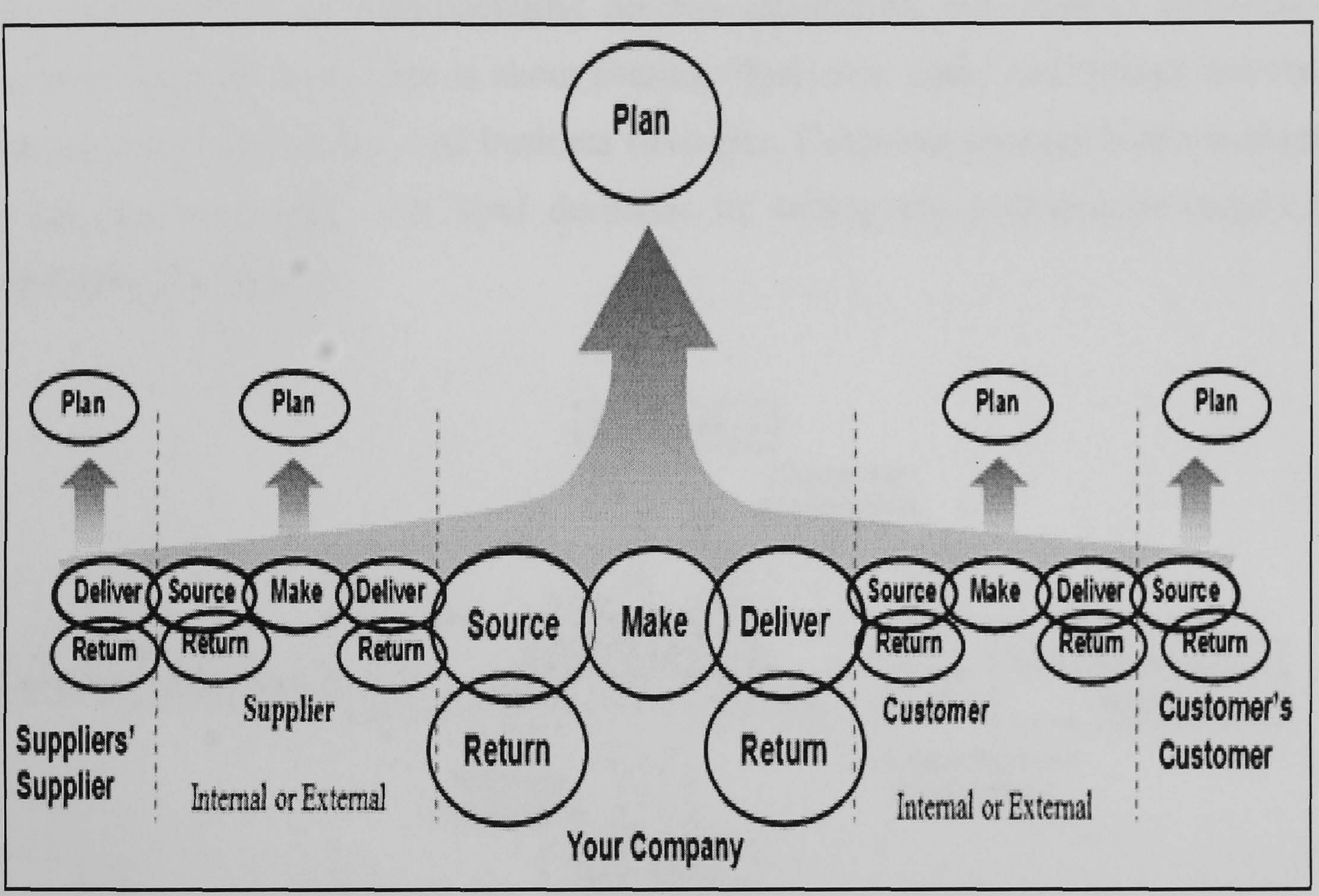

Figure 2.4: SCOR Model (Developed by Supply Chain Council)

Four different types of strategic integrations as shown in figure 2.5 have been identified in the value chain (Swink et al., 2007).

- Strategic Customer Integration
- Strategic Supplier Integration
- Product-Process Technology Integration
- Corporate Strategy Integration

Strategic customer integration is the process of acquiring customer requirements information and related knowledge. This provides a better understanding of the customer requirements and helps to develop a strong relationship with customer. Strategic supplier integration involves the process of acquiring and sharing operational and technical knowledge with the suppliers and vice versa. Product –process technology integration is the process of simultaneously developing product and processes and is pursued in manufacturing plants so that manufacturing processes may incorporate a better understanding of product requirements and similarly product designers may incorporate a better understanding of manufacturing process capabilities into product specification. Corporate strategy integration is about sharing objectives, plans and related knowledge pertaining to manufacturing and business strategies. Corporate strategy helps in aligning the business level and plant level decisions by setting the performance targets and deployment of resources.

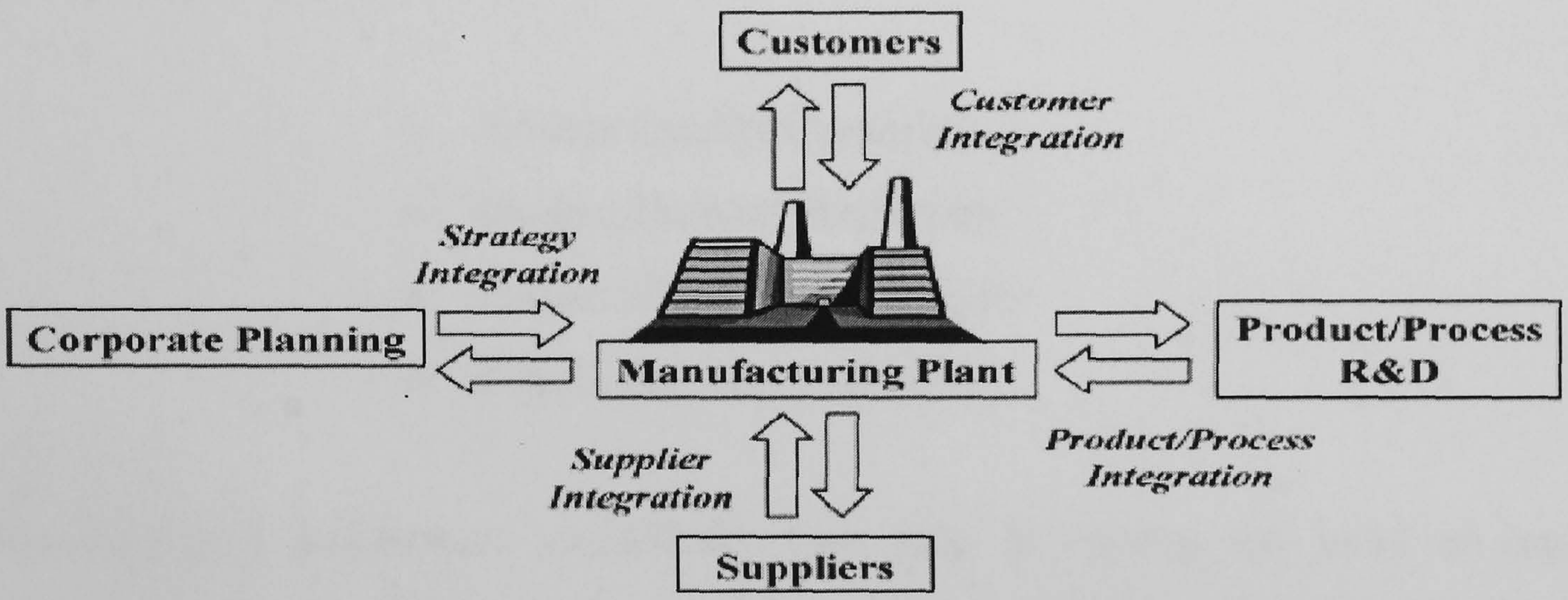

Figure 2.5: Types of Strategic Integration in Value Chain (Swink et al., 2007)

The decision regarding the extent of upstream and downstream integration by most of the manufacturers are implicit in nature. Some manufacturers have little integration with suppliers and customers and therefore have a relatively narrow arc of integration. On the other hand some manufacturers extensively integrate with their suppliers and customers thus having a broad arc of integration (Frohlich and Westbrook, 2001).

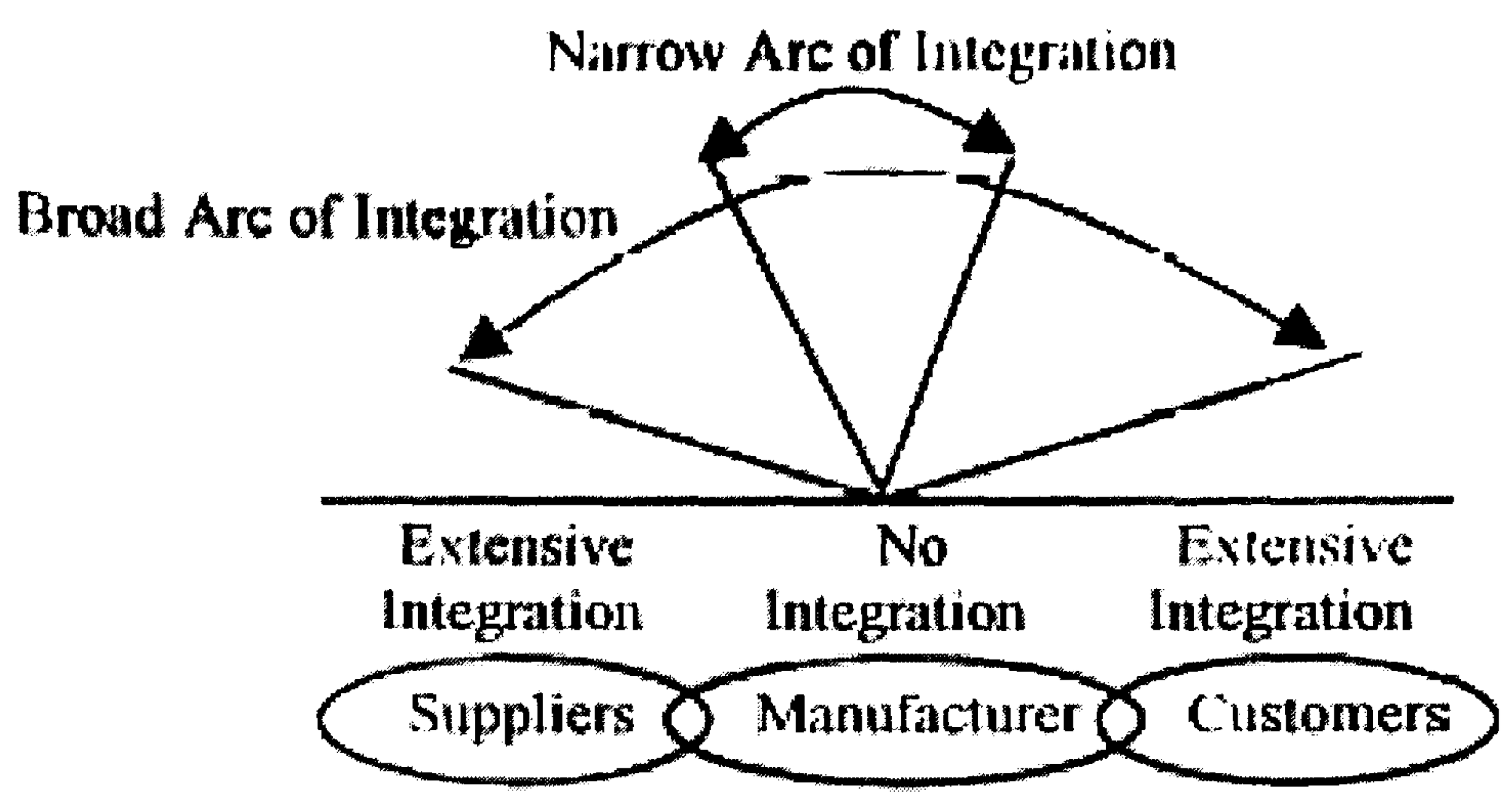

Figure 2.6: Arcs of Integration (Frohlich and Westbrook, 2001)

Growing evidence suggests that the higher the level of integration with suppliers and customers in the supply chain the greater the potential benefits. High supply chain integration intensity directly influences the following competitive capabilities as summarised below (Rosenzweig et al., 2003):

- Product Quality Capability
- Product Delivery Reliability
- Process Flexibility Capability
- Cost Leadership Capability

The improved competitive capabilities then help in raising the level of business performance by increasing sales growth, customer satisfaction and revenues from new products.

2.5 Strategic Use of Technology

Technology is recognised as a major decision area within manufacturing strategy (Hayes and Wheelwright, 1984; Skinner, 1985; Fine and Hax, 1985). Joseph Morone (1989) raised a series of critical question:

"Why do some companies bring technology to bear on the market more effectively than others? Within a given industry, in response to a given competitive environment, why do some firms build competitive advantage on the basis of technology, while others do not? Why do some firms build their strategies around technology based opportunities, while others do not?

The answer to all these questions is simply that successful firms emphasise more on the management of technology as compared to their less successful competitors (Morone, 1989). Technology is perhaps the most important single source of major market share changes among competitors and is the prominent cause of the demise of an entrenched dominant firm (Porter, 1983). Technology can create or destroy profits (Frohman, 1985) and have the ability to create new industries and transform or destroy the existing ones (Cooper and Schendel, 1988).

The link between technology and competitive advantage is well established in literature. Technology has featured in Porter's (1980) competitive strategy, Prahalad and Hamel (1990) core competency theory and is regarded as an important attribute of the 'Next Generation Manufacturing' according to NGM (1997) report. Technology is a great possibility and a threat to companies at the same time (Torkkeli and Tuominen, 2002). This implies that a company is in danger of loosing a competitive advantage if it invests in the wrong technology.

2.5.1 Relationship between Technology and Manufacturing

Technological innovation has been a powerful force for industrial development, productivity growth and indeed our rising standard of living throughout history (Abernathy and Clark, 1985). The advancement in the field of technology is phenomenal in the last century and more so in the last quarter of the century. Similarly the rate of development in the field of manufacturing technology has been extraordinary in the last decade and many new, advanced and user friendly programmes and tools have become available to manufacturing managers. The availability of these supporting programmes and tools has made a modern manufacturing manager more effective, efficient and agile. But on the other hand the modern manager is facing the dilemma of making the right choice between the available technologies as various manufacturing variables are closely linked with each other and have a complex interrelationship (Burbidge, 1984). There is hardly an industrial manager who is not touched by technological change and by the persistent challenge of technology planning and choice (Kleindorfer and Partovi, 1990). Tuominen and Torkkeli (2002) described selection of technology as one of the most challenging decision making areas the management of a company encounters.

2.5.2 The Big Question

Hayes & Wheelwright (1984) mentioned that the availability of more than one kind of manufacturing technology gives rise to the following questions:

1. *What kind of manufacturing technology is appropriate for a given situation (what particular capabilities must it have and what weaknesses or constraint can it afford to have if tradeoffs are required? How frequently should changes be made in the technology and what circumstances or events are likely to trigger them?*

2. *What procedures should be adopted to help identify, select and pursue the best opportunities for changing the firm's production technology? How should these changes be implemented and what organisational strengths are required to carry out the firm's strategy for technological improvement?*

Historically capital budgeting models are the mot common models for the purpose of technology selection in manufacturing (Diaz, 1986; Swindle, 1985). These models (Tipping et al., 1995; Bennett et al., 1997) are good for financial appraisal of technology but they fail to address long term strategic issues that correspond to the competitive environment facing manufacturing organisations internationally (Kleindorfer and Partovi, 1990). Shehabuddeen (2006) described current approaches to technology selection decision as narrowly focused on the assessment of financial viability of technology options or conventional investment justification factors. Furthermore there are many cases where the selection processes are intuitive and generic and are not fully suitable for technology selection.

2.6 Literature Relevant to the Technology Selection Process

The fact that technology is a source of competitive advantage is so widely accepted in the literature that it has become axiomatic (Morone, 1989). As mentioned earlier technology is recognised as a major decision area within manufacturing strategy (Hayes and Wheelwright, 1984; Skinner, 1985; Fine and Hax, 1985) and has received greater attention in the last few decades while formulating the manufacturing strategy.

The empirical research in technology selection and evaluation is relatively new and the work is predominantly exploratory. However it is an important area of study for the following reasons (Tingling and Parent, 2004):

- Technology accounts for one third of all business capital spending
- Evaluation and selection often precede adoption and use
- Technology evaluation inform theorists, providers, consumers and policy makers

Technology can be studied from various perspectives. Steele (1989) and Betz (1998) have classified technology into three dimensions (see Torkkeli and Tuominen, 2001):

- Product/ service technologies = Product Technologies
- Manufacturing/service-delivery technology = Production Technologies
- Information/operations technologies = Information Technologies

The above classification is useful in understanding the technology specific requirements for the selection process and the supporting tools used in the process. Most of the researchers have not considered technology in the fully developed physical shape that is available for them to achieve their desired goals. They have considered technology as know-how rather than a physical entity (Shehabuddeen, 2006). This is the reason that most of the literature on technology selection focuses mainly on selection of technology for R&D purposes (Stillman, 1997; Twiss, 1995; Tipping et al., 1995).

Different researchers have used different criteria for the technology selection. Yap and Souder (1993) emphasised to include the resources needed to develop technologies, contribution of technology to the company, current life cycle stage of the technology and the funding history of the technology in the technology selection model. Gagnon and Haldar (1997) selection criteria included alignment with the goals, competitiveness, long term viability and financial viability. This means the selected technology fits well with the business objectives, gives the company a competitive edge, is a mature technology and last but not the least increases the profitability. The selection criterion of Chatterji (1996) is based much on cultural issues and technical merits of the technology. Edosomwan (1989) defined a comprehensive list of factors that should be considered for technology selection that included characteristics of technology, impact of new technology on organisation, cost and time horizon. Piipo and Tuominen (1990) have advocated in favour of strategic alignment between the capabilities and strategies of the company and selected technology in addition to the financial benefits.

2.6.1 Existing Technology Selection Frameworks

The majority of the technology selection frameworks address the financial aspects related to the technology selection process. They have been popular in the industry because of their easy to use nature, rational tactical financial assumptions and their treatment of the time value of money (Kleindorfer and Partovi, 1990). Although these models have been helpful in the selection of technology when the financial constraint is the biggest concern, they do not incorporate key strategic issues in their decision making framework for technology selection for a modern manufacturing company or a supply chain. Due to globalisation the manufacturing companies are competing with each other on the global scale, so they require a comprehensive technology selection framework which not only takes account of the financial viability of the technology in question but also considers the acceptance of the technology by the supply chain members as a tool that will provide the supply chain a competitive advantage.

2.6.1.1 Kleindorfer and Partovi Technology Selection Methodology

Kleindorfer and Partovi (1990) presented the methodology for the technology selection in manufacturing organisations. The proposed methodology starts with the competitive strategy analysis that is the building block for the formulation of manufacturing strategy. This helps in defining the importance of cost, quality, flexibility and dependability for long run profitability and competitive viability. These considerations lead then to the development of performance hierarchy for a given line of business. Eventually it is the performance hierarchy evaluation based on the analytical hierarchy process (Saaty, 1982) that leads to a proposed procedure for prioritising alternative technologies.

The methodology consists of five stages (figure 2.7) namely formulation of the mess, ends planning, means planning, resource planning and implementation. Formulation of the mess is basically the 'SWOT' analysis of the company. The process includes the value chain analysis which is based on the idea of a process view of organisation which means viewing a manufacturing organisation system made up of subsystems with inputs, transformation processes and outputs. The second stage of the methodology is the ends planning. This phase includes the definition of desirable characteristics of a product line from a marketing or consumer perspective. These characteristics are converted into manufacturing performance objectives in terms of cost, quality, flexibility and dependability. The output of ends planning is a specification of desirable performance objectives to be met by available product or process technologies. The third stage of this methodology is called means planning and is directed at a detailed evaluation of specific technologies. The final two stages of the current methodology are resource planning and implementation. Resource planning is linked with resources required and ways of generating them, whereas the implementation process is concerned with implementing the proposed technological planning process.

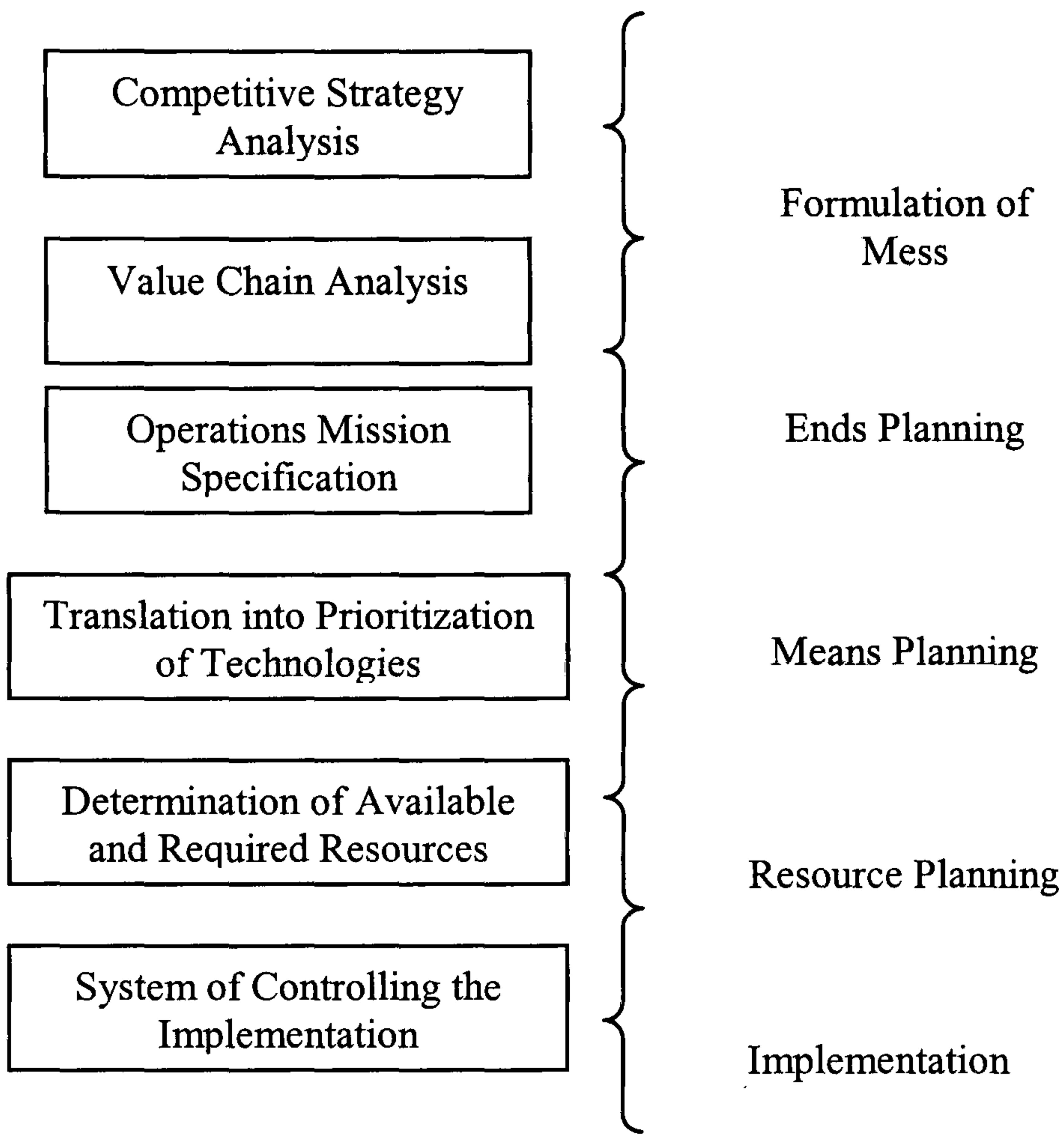

Figure 2.7: Kleindorfer and Partovi Technology Selection Methodology (1990)

2.6.1.2 Yap and Souder Technology Selection Model

The model presented by Yap and Souder (1993) combines the analytical aspects of technology selection decisions with the impacts of behavioural and organisational processes on these decisions and interaction between these impacts and various external environmental factors. They introduced a filter system for decision analysis for technology selection.

The basic concept of the filter system is that various types of decision analysis and information is required for an effective technology selection process. These requirements mostly derive from characteristics of the candidate technology, technologies interrelationships, decision making and communication processes, mission and goals, cultural and human aspects and environmental factors. The filter system consists of the elimination filter and the technology selection procedure. The elimination filter is the first stage that the candidate technologies have to pass, if successful they will be evaluated using the technology selection procedure otherwise they bow out after the first round. The selection procedure is much more in detail and rigorous and is applied to only those technologies who have survived the first stage. The filter system consists of a strategic fit screen, competitive environment screen, technological environment screen and market environment screen. The function of the strategic fit screen is to analyse that candidate technologies align well with a company's overall strategic objectives. A panel of financial, manufacturing and marketing personnel are involved in this stage of analysis. The competitive environment screen is used to assess the competitive barriers facing a candidate technology. The process is employed to judge the performance of the candidate technology with that of a competitor's technology. Participation of technical experts is needed in this stage for the evaluation of a candidate technology with a competitor's technology and also to analyse their development stage. The function of the technological environment screen is to examine the ability of the company to pursue the technological advantage by supporting the push towards state of the art technology in the form of motivation of workers, skill level and experience of its researchers, the availability of facilities and equipment and the management attitude towards risk. Finally the market environment screen considers components from both external environments as well as internal environment within a company. The external environments can benefit directly or indirectly from adopting the technology. The example of a direct advantage can be the creation of a marketable new product. An example of an indirect benefit would be the ability to produce an existing product more efficiently. The internal market environment for a candidate technology consists of personnel within the organisation who will benefit from the technology. They may be the R&D staff, the maintenance personnel or the ultimate users. At the end of the technology selection, a procedure is employed that uses a linear programming model as a solution algorithm for selecting the technologies. The model assumes that the objective is to select the technology which is beneficial to the organisation. This conceptual objective is converted into a hierarchy of measurable sub-objectives. The purpose of decomposing the conceptual objective into operational sub-objectives is to achieve greater objectivity.

2.6.1.3 Khouja Technology Selection Model

Khouja (1995) presented a technology selection model making use of data envelopment analysis (DEA). The model consisted of two phases with phase 1 identifying the technologies available for selection purpose using the DEA method and phase 2 involving a multi attribute decision making process to select the technologies identified in phase 1.

In phase 1, starting with a set of feasible technologies the most suitable technology was identified keeping in mind the operating performance of a technology in the production system that may include high temperature, radiation and humidity etc. Moreover the financial constraints associated with the technologies also played a significant role in the identification process. The identified technologies were then evaluated using a multi attribute decision making framework.

2.6.1.4 Mohanty and Deshmukh Technology Selection Framework

The Mohanty and Deshmukh (1998) framework consisted of strategic objective settings, identification of advanced manufacturing technologies, identification of attributes for advance manufacturing technologies and finally the evaluation of advanced manufacturing technologies.

The process starts with the formation of a group which is aided by a facilitator to identify the objectives of advanced manufacturing technologies by using nominal group technique (NGT). Similarly the attributes of evaluation of advanced manufacturing technology and advanced manufacturing technology alternatives are determined using NGT. The next step is the development of an analytical hierarchy process (AHP) decision making hierarchy and evaluation of identified technologies against defined attributes using the AHP methodology. The concept of quality confidence interval (QCI) is then employed to minimise the fuzziness in the decision making process. The application of quality confidence interval is emphasised because the decision makers might not be able to replicate their AHP weight assessments and therefore will give rise to variation in technology rankings.

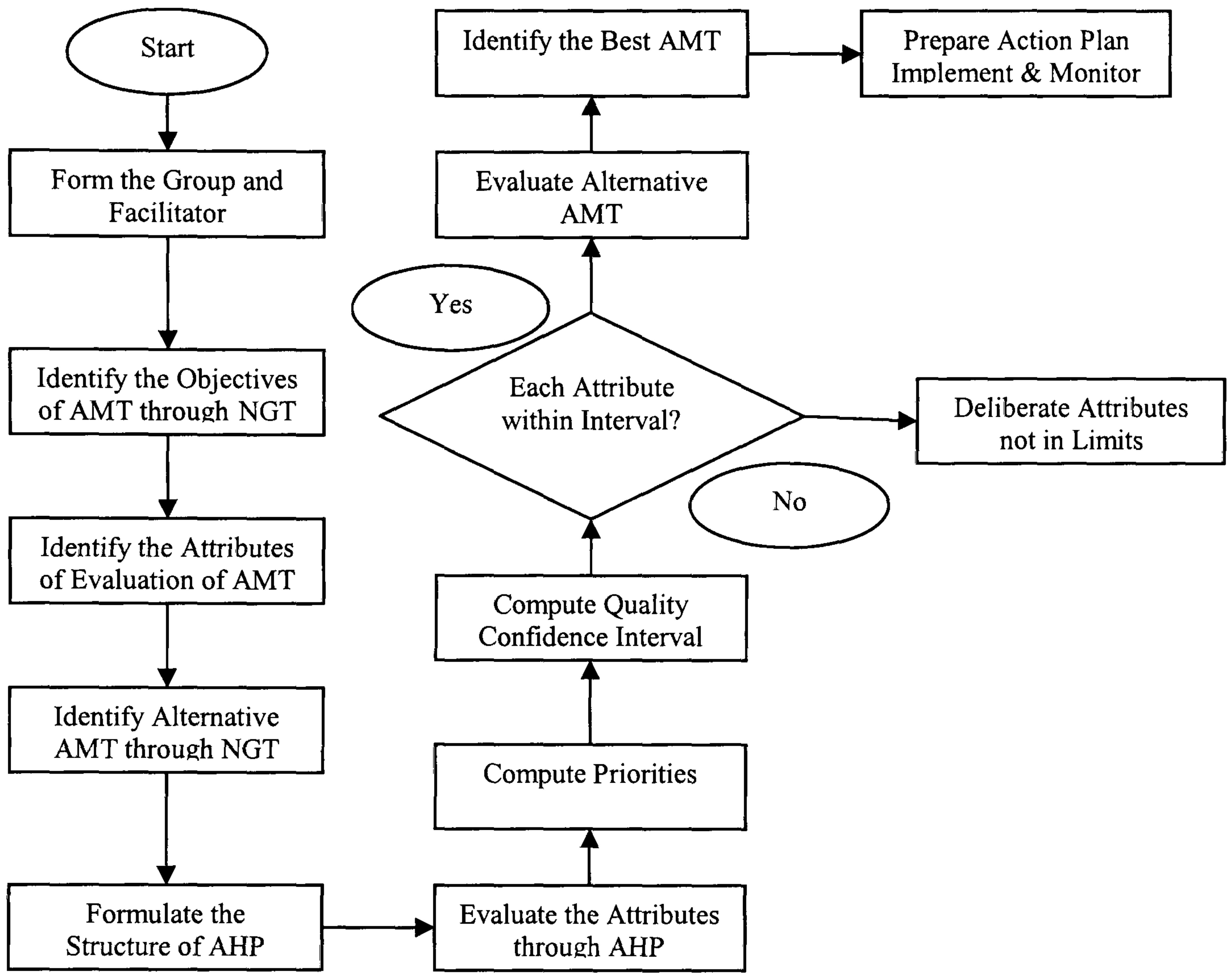

Figure 2.8: Mohanty and Deshmukh Technology Selection Framework (1998)

2.6.1.5 Lowe, Ridgway and Atkinson Technology Selection Tool

Lowe, Ridgway and Atkinson (2000) presented a technology selection tool using 'Quality Function Deployment' (QFD) for semi-solid metal processing technology (thixoforming). The purpose of the process was to provide a cost benefit analysis of thixoforming technology using a business process perspective.

A simplified form of 'House of Quality' (HOQ) is used in this technology selection tool. A selected product is evaluated against the thixoforming technology by placing the characteristics of the product in the customer requirement side of the standard HOQ. The characteristics of the thixoforming technology are placed in the technical requirement column of a standard HOQ. The interrelationship matrix is then used to determine the relationship of different product characteristics with characteristics offered by the thixoforming technology. The relative interdependency scores are then calculated to determine the overall prioritised thixoforming characteristics score.

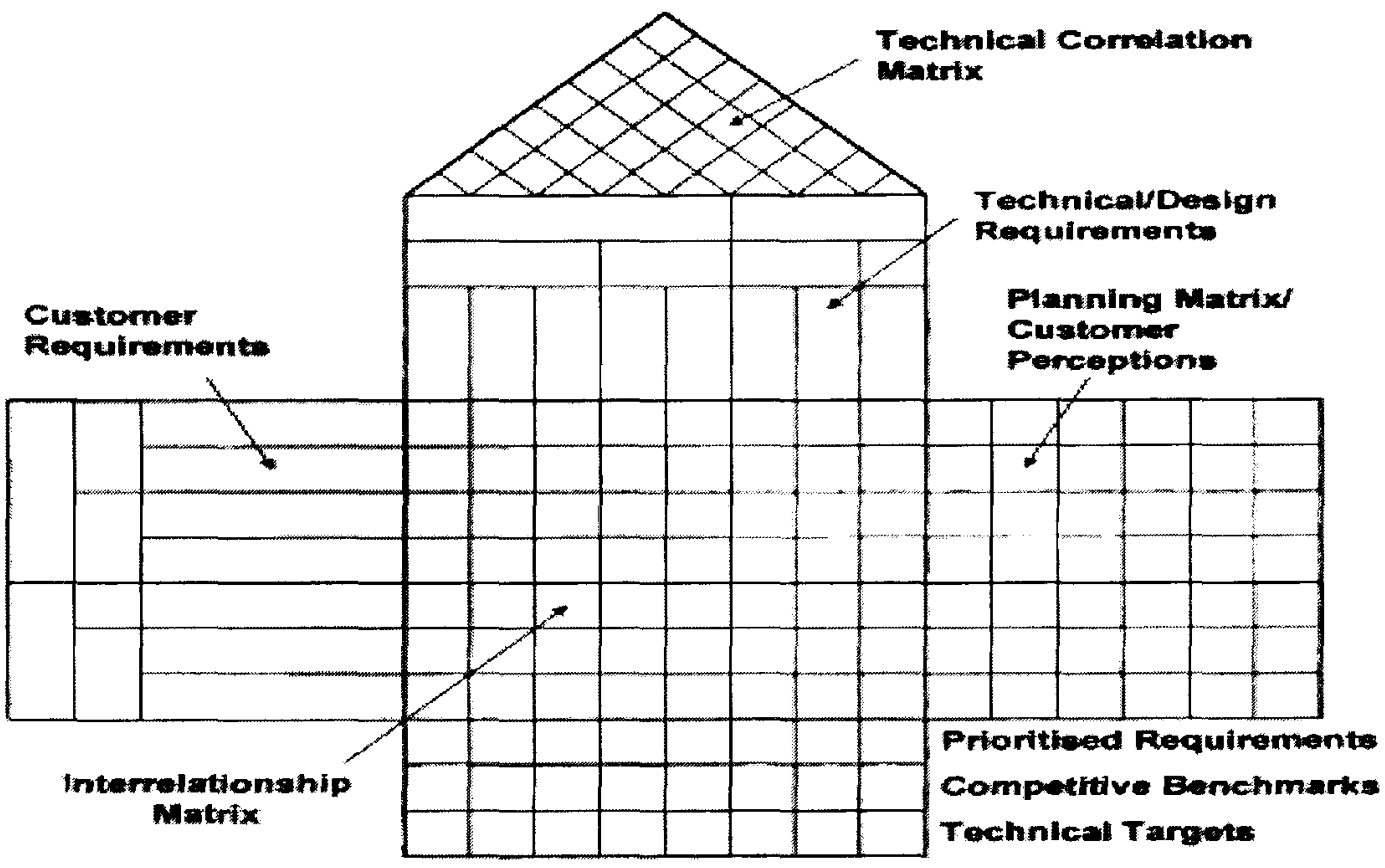

Figure 2.9: Standard House of Quality (HOQ)

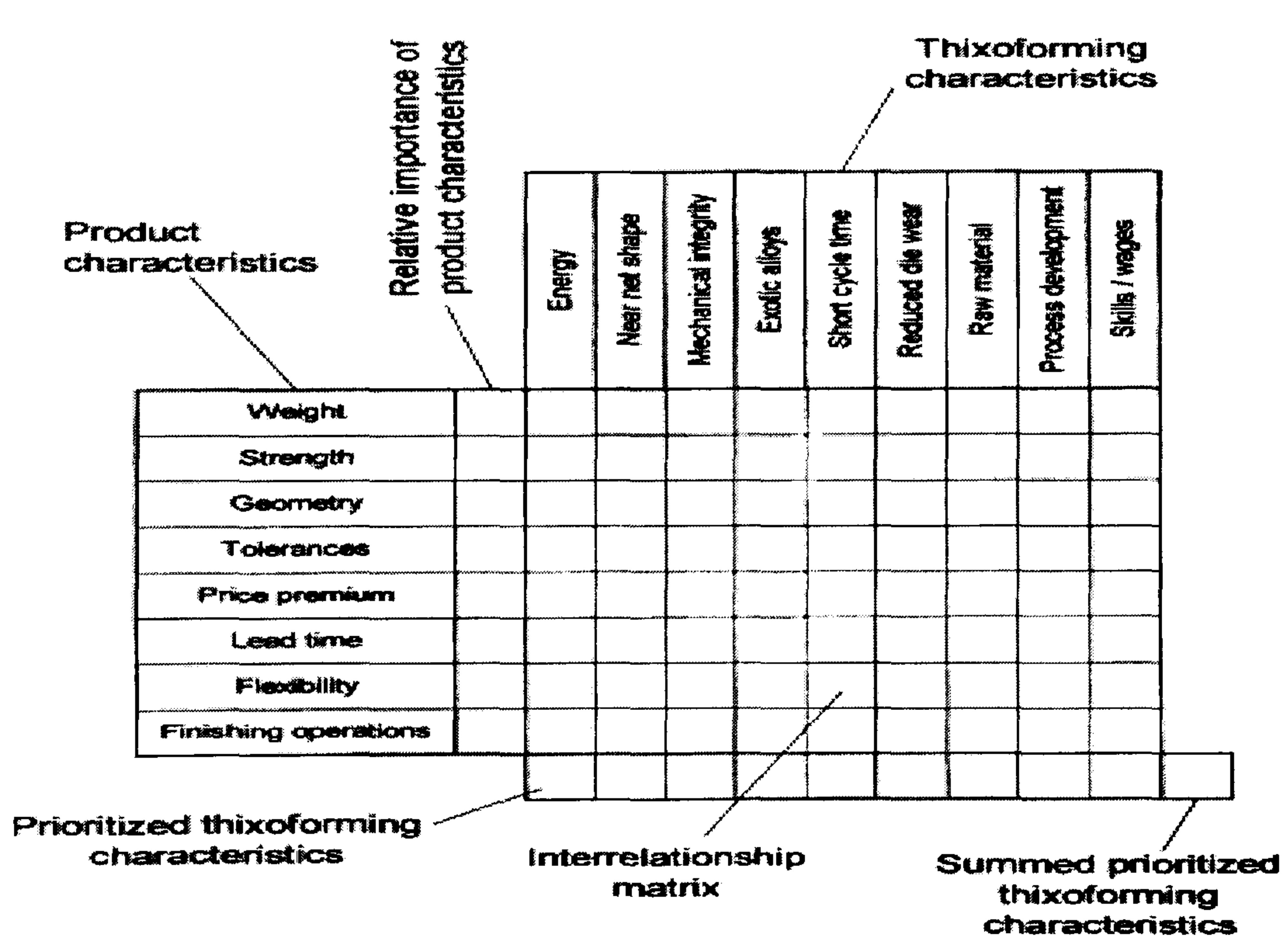

Figure 2.10: Lowe et al. Technology Selection Tool (2000)

2.6.1.6 Kengpol and O'Brien Technology Selection Tool

The technology selection tool presented by Kengpol and O'Brien (2001) highlighted the need for a decision support tool that can integrate different decision making models to achieve a comprehensive evaluation of the technology alternative.

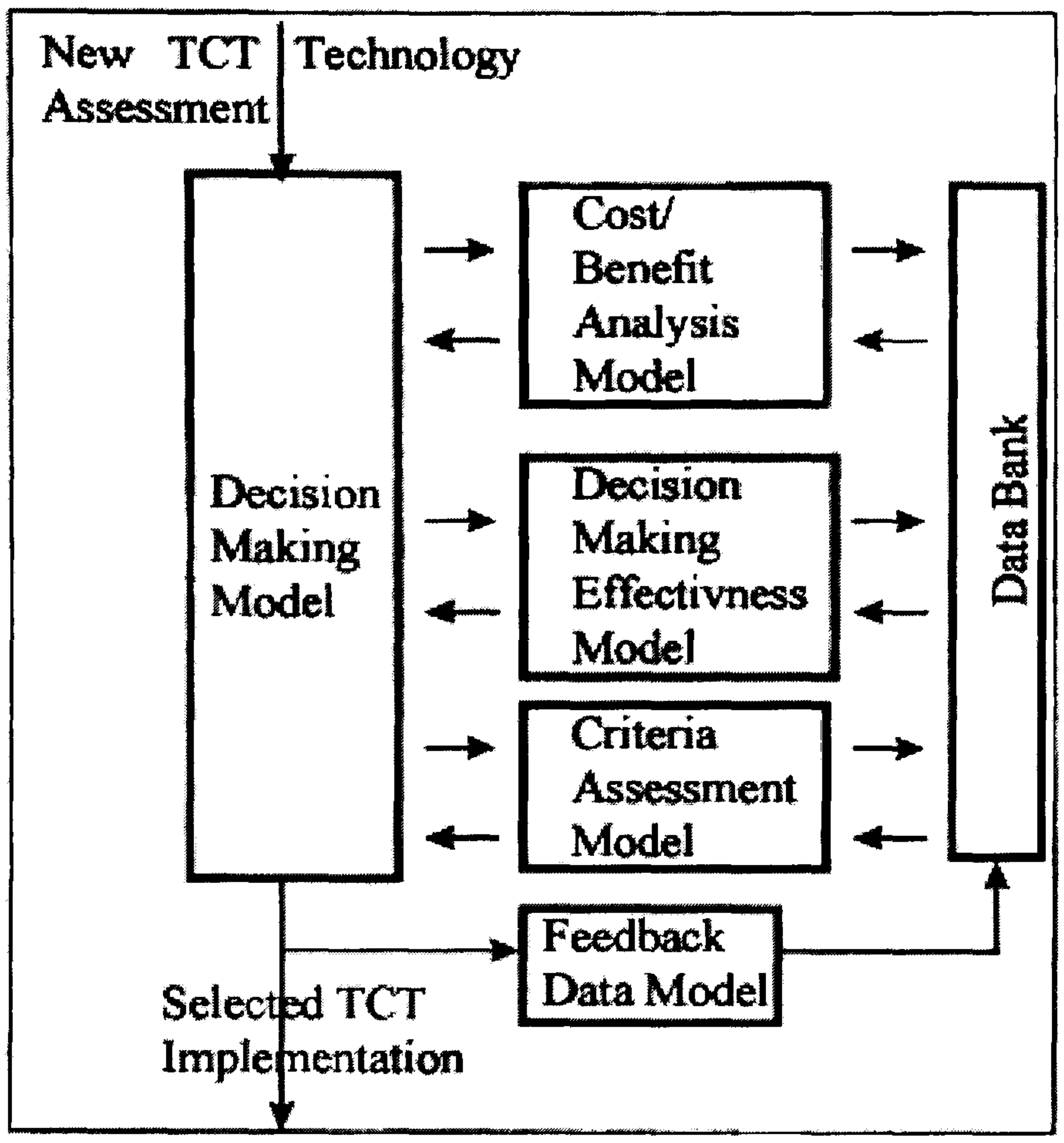

Figure 2.11: Kengpol and O'Brien Technology Selection Tool (2001)

The three decision models are supported by the data bank where all the data is kept and is communicated to the 'Cost Benefit Analysis Model', 'Decision Making Effectiveness Model' and 'Criteria Assessment Model' in a structured way. Cost benefit analysis is carried out by the 'Neutraline Profitability Model' which is an anticipated cash flow using the illustrative data for current technology and business practice. The neutraline profitability model consists of a revenue section, an expenses section and a profit section for the cost benefit analysis. The decision making effectiveness model leads to the probability of technology success. A logistic regression model is suggested for assessing the probability of technology success. A logistic regression model uses past data to estimate the probability of future success. The criteria assessment model consists of tangible and intangible criteria that can influence the technology selection process. Analytical Hierarchy Process (AHP) methodology is advised for prioritisation of the criteria identified for the technology selection process.

2.6.1.7 Torkkeli and Tuominen Technology Selection Process

Torkkeli and Tuominen (2002) presented their process of technology selection from a core competency perspective. They documented a seven phase process consisting of a number of sequential steps for the technology selection and its impact on core competency.

The first phase is the identification of the existing core competencies. The main purpose of this phase is to assess the present situation of the company. The process involves the participation of the managers from all over the company who are related to this process in one way or the other. The main outcome of the process is the list of existing core competencies. This output serves as an input to the next phase that describes the establishment of core competence agenda. The main output of this phase is the requirement for technologies. The third phase is the identification of alternative technologies and the output of the process is the list of possible technologies to be developed or acquired and the characteristics of the technology alternatives. The fourth phase describes the mapping of the selection criteria and determination of their importance is carried out. Criteria fulfilling the business goals as well as technological specifications are needed to be created to test the most desirable technology. The fifth phase is the assessment of alternative technologies already identified in the process and find out the best assessed core competency integrated technology. The sixth phase analyses the selected technology in different scenarios such as in different operations and in different departments of the company. The last phase of the selection process ensures that the selected technology strengthens the core competencies in the best possible way.

INPUT →	THE PHASES OF THE PROCESS	→ OUTPUT
• Purpose and tasks of the technology to be selected • Determination of relevant participants (people representing the key functions, all business units, important cross functional or cross-SBU teams and important projects) • Business goals of the company • Business strategy of the company	1. IDENTIFICATION OF EXISTING CORE COMPETENCIES (See questions 1 to 8 described in chapter 3.2)	• List of existing core competencies and technologies • Components of company's core competencies • Linkages between core competencies and competitive advantages of company • Duration of competitive advantages • Trends in the industry • Redefined business strategy
• Existing core competencies and technologies • Competence-product matrix	2. ESTABLISMENT OF THE CORE COMPETENCE AGENDA	• Existing and new competencies and products matrix • Requirements for technologies
• Knowledge of experts • Planned application areas and tasks for technology • Requirements of different SBUs for technology	3. IDENTIFICATION OF ALTERNATIVE TECHNOLOGIES	• List of possible technologies to be developed or acquired • Characteristics of technology alternatives
• Business goals of the company • Experts' knowledge and opinions about importance of different requirements and competencies	4. MAPPING OF SELECTION CRITERIA AND DETERMINATION OF THEIR IMPORTANCE	• List of criteria • Classified criteria in the evaluation categories • Distribution of experts' evaluations on importance of criteria
• Information and knowledge from different SBUs • Experts' knowledge and opinions about capabilities of alternatives to fulfill criteria	5. ASSESSMENT OF ALTERNATIVE TECHNOLOGIES	• Distribution of experts' evaluations on capabilities of alternatives to fulfill criteria • Fulfillment of criteria • Total weighted points • The best assessed technology
• Assessment results of alternatives • The most important criteria • Additional arguments and opinions of participants • Technology portfolio • Requirements and opinions of participants for the selected technology	6. ANALYSIS OF RESULTS AND SELECTION OF TECHNOLOGY Select best possible technology, which strengthens competencies (bundle of technologies, portfolio)	• Impact of the selected technology on different operations and departments of the company • Means to avoid the negative impacts of the failed criteria
• Market-competence matrix • Leverage areas of technology • Technology vulnerability • Potential partners and alliances	7. DEPLOYMENT, PROTECTION AND DEFENDING OF CORE COMPETENCIES	• Needed future development • Regular "competence review" • Possible opportunities for achieving new markets or making new products • Sustainable competitive advantage

Figure 2.12: Torkkeli and Tuominen Technology Selection Process (2002)

2.6.1.8 Punniyamoorthy and Ragavan Technology Selection Model

The technology selection model presented by Punniyamoorthy and Ragavan (2003) considers tangible and intangible factors for technology selection process. The tangible factors are represented by time and cost and intangible factors are identified by the technology managers and are evaluated using the Analytical Hierarchy Process (AHP).

In this model both the subjective and objective factors are converted into consistent and dimensionless indices to measure the manufacturing system preference measure. The objective factors that include time and cost calculations are measured by using an extended form of the Brown and Gibson (1972) facility site selection model. The subjective measure of the intangible factors required the senior managers to identify the factors that influence the technology selection process. The determination of objective and subjective factors is used for calculating manufacturing system preference measure to identify the suitable technology alternative.

2.6.1.9 Shehabuddeen, Probert and Phaal Technology Selection Framework

Shehabuddeen et al. (2006) presented framework for technology selection based on the filter scanning technique. He proposed two filters for technology selection namely requirements filter and adoption filter.

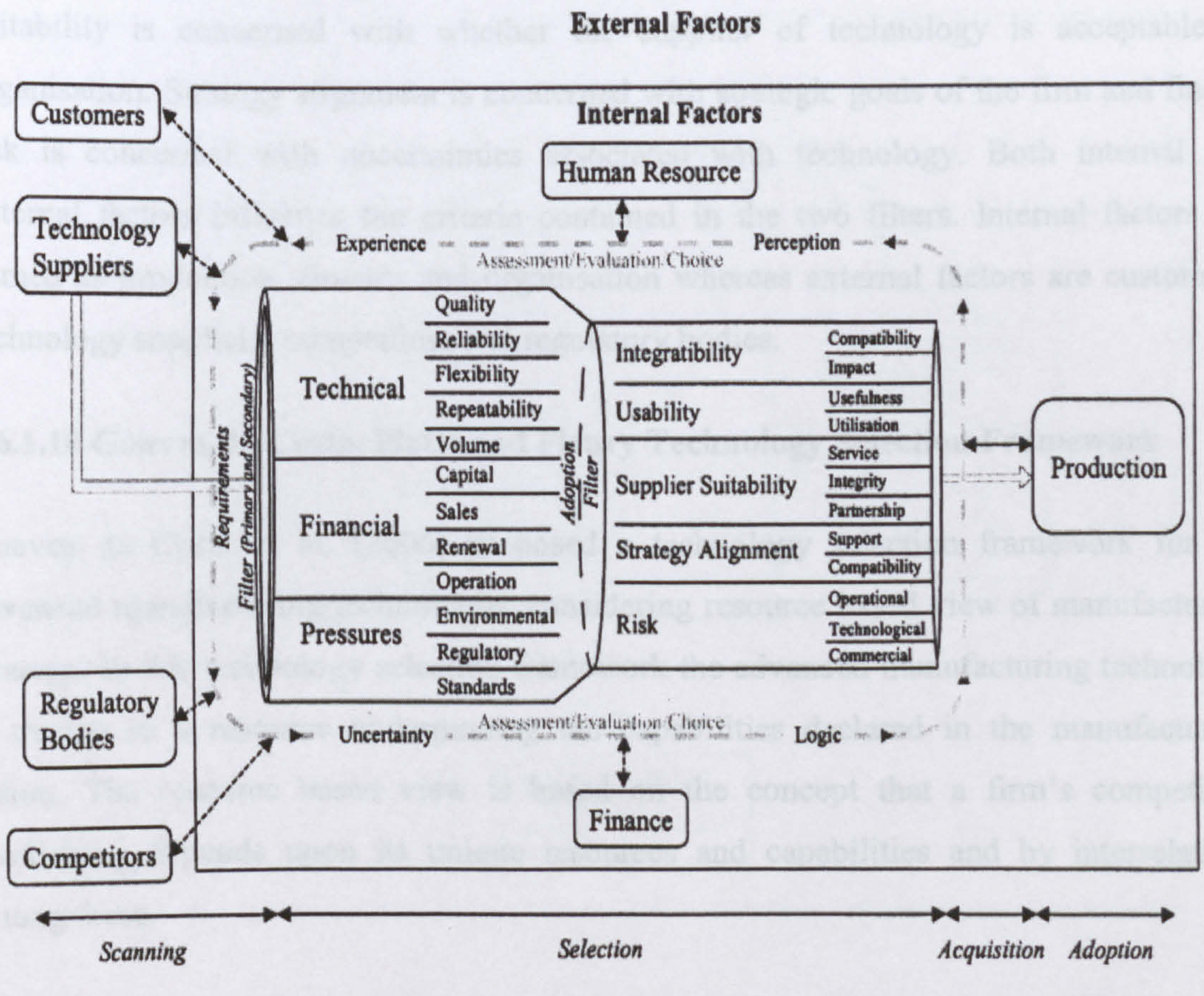

Figure 2.13: Shehabuddeen et al. Technology Selection Framework (2006)

The first filter is the requirement filter based on the requirements that are critical to the success of the technology selection project and requirements that are desirable but not essential. The requirement criterion is grouped into three categories: technical, cost and external pressures. The technical criteria is further divided into quality of products delivered by the technology, the reliability of the technology and the volume of production possible using the technology. Similarly cost criteria include cost of ownership of technology, capital cost of technology and cost of operation of technology. External pressures criteria include environmental pressures and the regulatory pressures that the technology could help to resolve. The second filter in the framework is the adoption filter. After passing through the first filter technologies have to be evaluated for their suitability for adoption in the organisation. The adoption filter is categorised into integratability, usability, supplier suitability, strategy alignment and risk. Integratability is concerned with the integration of technology in the organisation. Usability indicates whether the technology can be utilised for its intended purpose. Similarly supplier suitability is concerned with whether the supplier of technology is acceptable to organisation. Strategy alignment is concerned with strategic goals of the firm and finally risk is concerned with uncertainties associated with technology. Both internal and external factors influence the criteria contained in the two filters. Internal factors are named as production, finance and organisation whereas external factors are customers, technology suppliers, competitors and regulatory bodies.

2.6.1.10 Gouvea da Costa, Platts and Fleury Technology Selection Framework

Gouvea da Costa et al. (2006) proposed a technology selection framework for the advanced manufacturing technologies considering resource based view of manufacturing strategy. In this technology selection framework the advanced manufacturing technology is treated as a resource underpinning the capabilities declared in the manufacturing vision. The resource based view is based on the concept that a firm's competitive positioning depends upon its unique resources and capabilities and by interrelations among these.

The proposed framework consists of five phases and each phase consisted of several steps. The first phase of the framework is defined as the market requirements and consists of six steps to evaluate the market requirement of an advanced manufacturing technology. The second phase is called the current manufacturing system comprising of four steps for evaluating the needs of the current manufacturing system. The third phase is defined to determine the relationship between the manufacturing vision and the advanced manufacturing technology and consisted of six steps. The relationship between performance measurement system and advanced manufacturing technology is described in phase four and consists of three steps. Finally the alignment between the manufacturing strategy and advanced manufacturing technology is determined in phase five using four steps. The framework is then operationalised using a process approach developed by Platts et al. (1996).

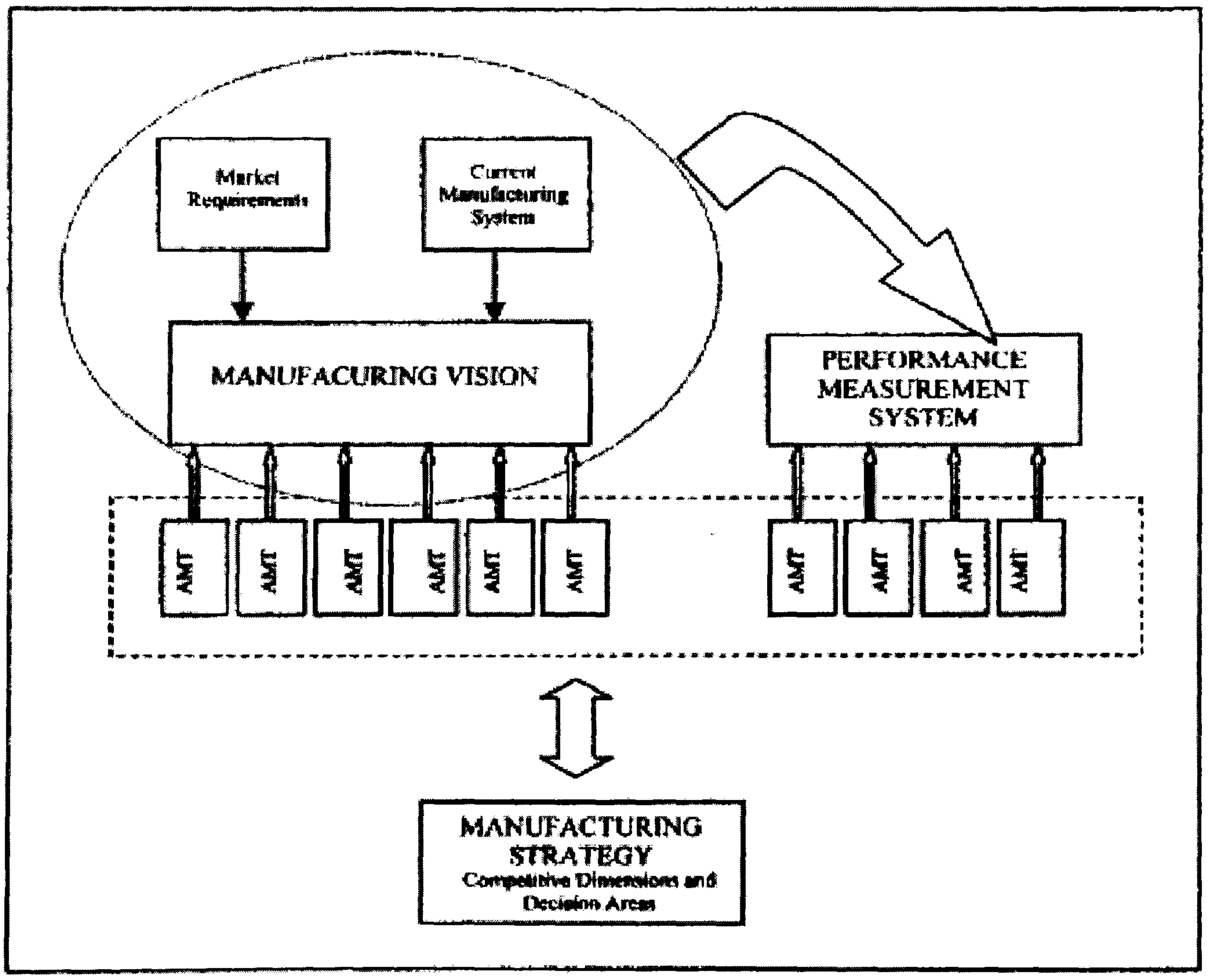

Figure 2.14: Gouvea da Costa et al. Technology Selection Framework (2006)

2.7 Shortcomings of the Existing Frameworks, Processes and Tools

Traditionally technology selection models have been developed to assess the financial benefits of the candidate technology. This is the main reason they have been subjected to criticism over the period of time. Kleindorfer and Partovi (1990) reported growing concern of the inability of these models to deal with

- Multi objective decisions
- Non monetary factors in technological decision making
- Environmental uncertainties and estimation inaccuracies

The technology selection frameworks presented in this chapter and the other available technology selection frameworks in literature fail to incorporate risk associated with technology alternatives while considering them for strategic selection. Similarly the techniques available for technology selection have not included the threats associated with a technology alternative while considering it for strategic selection. The emergence of global supply chains seems to have eluded the technology selection researchers. The literature does not provide any study that incorporates the importance of the supply chain in the technology selection decision making process. From the perspective of manufacturing organisations which are dependent on advanced manufacturing technologies for their competitive advantage and which are having extended supply chains the existing technology selection processes provide no direction for their technology selection so that not only are their manufacturing objectives fulfilled but also the selected manufacturing technology plays a positive role in achieving the objectives of the supply chain.

2.7.1 Gaps in Existing Literature

By reviewing the existing literature on manufacturing strategy, supply chain strategies and decision making in manufacturing technology selection the following gaps can be identified in the existing literature:

1. There is limited empirical research showing the operationalisation of the manufacturing strategy process.

2. The topic of supply chain integration is discussed feverishly in the literature but the process of supply chain integration is not demonstrated.

3. The technology selection processes fail to incorporate risk calculations in strategic technology selection.

4. The threats associated with a technology alternative have not been considered in the technology selection process and their importance in technology evaluation is neglected.

5. The existing technology selection processes do not provide support for the inclusion of inter-organisational factors in the technology selection decision making environment.

2.8 Conclusion

Reviewing the literature on manufacturing strategy reveals that much has been said and done regarding setting the manufacturing objectives and gaining competitive advantage using manufacturing as a strategic weapon. But there is very little indication regarding the process (operationalisation/formalisation) side of manufacturing strategy. This research takes Hayes and Wheelwright (1984) original manufacturing strategy framework as a reference for understanding the basic relationship between the content and process side of manufacturing strategy and then identifies a manufacturing objective and documents the process of achieving the identified manufacturing objective. Hayes and Wheelwright's set of world class manufacturing practices have stood the test of time (Flynn et al., 1999). Despite of the fact it was presented two decades ago, it is still widely used in research and practice (Boyer and Lewis, 2002). This study considers 'technology' as the major decision area within manufacturing strategy that can provide a competitive edge to the company. The field of supply chain has evolved rapidly in the last few decades. As more and more companies are going global, so they are forced to think beyond the four walls of their company. This research introduces the concept of integrating manufacturing and supply chain in a single decision making loop while making strategic decisions regarding the selection of a manufacturing technology. A technology selection decision making framework is developed in this research and it aims to answer the gaps identified in the existing literature.

This chapter has presented the existing literature on manufacturing strategy, supply chain and technology selection. Technology selection frameworks available in the literature are discussed. The gaps in the existing literature that provided the input for technology selection framework developed in this research are highlighted. The next chapter introduces the research methodology adopted for this study and provides a detailed justification of the research methodology selected.

Chapter 3

Research Methodology

3.1 Introduction

This chapter describes the research methodology adopted for the research. The chapter starts with a brief introduction of different research paradigms. Considering the objectives of the research, action research (AR) is identified as the appropriate methodology for this research. In this chapter a detailed justification of AR methodology is presented, research design and research process are explained and the reliability and validity of this research are discussed.

3.2 Theoretical Foundation

The identification of relevant and applicable research paradigms is central to the research process for the successful conduct of the research. According to Wittgenstein (1961), a paradigm is basically a 'world view'. People view the world differently (Naslund, 2002), thus for the sake of a successful study it is important to identify the research paradigm in which the research work can be placed.

There has been a long debate among the researchers as to 'how' and 'when' two fundamentally different research paradigms should be used to conduct a research. The two research paradigms are:

1. Positivist Paradigm
2. Phenomenological Paradigm

	Positivist paradigm	Phenomenological paradigm
Basic beliefs	• The world is external and objective • Observer is independent • Science is value-free	• The world is socially constructed and subjective • Observer is part of what is observed • Science is driven by human interests
Researcher should	• Focus on fact • Look for causality and fundamental laws • Reduce phenomena to simplest elements • Formulate hypotheses and then test them	• Focus on meanings • Try to understand what is happening • Look at the totality of each situation • Develop ideas through induction from data
Preferred methods include	• Operationalising concepts so that they can be measured • Taking large samples	• Using multiple methods to establish different views of phenomena • Small samples investigated in depth or over time

Table 3.1: Positivist and Phenomenological Paradigms (Easterby-Smith et al. 1997)

Several different names and terms have been in practice as alternatives for the main research paradigms as shown in table 3.2.

Positivist Paradigm	Phenomenological Paradigm
• Quantitative	• Qualitative
• Objectivist	• Subjectivist
• Scientific	• Humanistic
• Experimentalist	• Interpretivist/Hermeneutic
• Traditionalist	
• Hypothetico Deductive	• Inductive
• Social Constructionism	

Table 3.2: Alternative Terms for Main Research Paradigms (Mangan et al. 2004)

A wide variety of methodologies are available under the umbrella of positivist and phenomenological paradigms that are described in table 3.3

Positivist Paradigm	Phenomenological Paradigm
• Cross Sectional Studies	• Action Research
• Experimental Studies	• Case Studies
• Longitudinal Studies	• Ethnography
• Surveys	• Construct Elicitation
• Models and Simulation	• Grounded Theory
• Hypothetico Deductive	• Hermeneutics
• Social Constructionism	• Participative Enquiry

Table 3.3: Methodologies used in Positivist and Phenomenological Paradigms (Hussey and Hussey, 1997)

The main aims of this research are:

1. To develop a decision making framework for manufacturing technology selection incorporating manufacturing and supply chain considerations in a single decision making loop.

2. To develop a link between the content and process side of manufacturing strategy using a technology selection framework as an example.

3. To demonstrate that manufacturing technologies simultaneously provide different opportunities and threats that contribute towards their evaluation.

4. To demonstrate that the risk associated with the manufacturing technology plays a significant role in the selection of a strategic technology alternative.

5. To test and refine the technology selection framework using practical company case studies.

In order to satisfy the above research aims it is essential to consider a research paradigm and research methodology that does not detach the researcher from the subject that is under study and also provides an opportunity to the researcher to become a participant in the subject that is being researched. Thus for this research the phenomenological approach using action research methodology is deemed most suitable. The next section provides a detailed explanation of action research as a research methodology.

3.3 Action Research Methodology

Action research (AR) can be seen as a variant of case research. The major difference between the two research approaches is that in case research the researcher is independent whereas in case of action research the researcher becomes a participant in the implementation of a system and the process of change becomes the subject of research (Benbasat et al., 1987).

3.3.1 What is AR?

Several authors have broadly defined characteristics of AR. They can be summarised according to Coughlan and Coghlan (2002) as:

- Research in action rather than research about action
- Participative
- Concurrent with action
- A sequence of events and approach of problem solving

The main attribute of the AR is that it uses a cyclical four step process of planning, taking action, evaluating the action leading to further planning. It is participative in nature as the members of the system under investigation participate actively. This is in contrast with traditional research where members of the system are objects of investigation.

3.3.2 Why AR?

AR focuses on knowledge in action whereas positivist science is based on creation of universal knowledge. The major differences between AR and positivist science are documented in table 3.4.

	Positivist Science	**Action Research**
Aim of Research	• Universal Knowledge • Theory Building and Testing	• Knowledge in Action • Theory Building and Testing in Action
Type of Knowledge Acquired	• Universal • Covering Law	• Particular • Situational • Praxis
Nature of Data Validation	• Context Free • Logic Measurement • Consistency of Prediction and Control	• Contextually Embedded • Experiential
Researcher's Role	• Observer	• Actor • Agent of Change
Researcher's Relationship to setting	• Detached Neutral	• Immersed

Table 3.4: Comparison of Positivist Science and AR (Susman and Evered, 1978)

The production and operations management (POM) community has emphasised more on mathematical modeling and have deemed empirical research as less esteemed resulting in a big gap between operations management theory and practice (Flynn et al., 1990). This debate on POM research is very familiar and can be summarised by Westbrook (1995) as:

1. POM research has been traditionally based on modeling techniques that have been helpful for many cost saving applications for businesses and governments but the wider relevance of such models to most operations managers has been questioned.

2. The major developments in the field of POM (JIT, TQM) in last decade have been by the practitioners rather then the POM academics.

3. Perspective solutions to well defined problems have been pursued at the expense of broader contributions to theory. Partly for this reason POM remains relatively poor in theoretical developments.

4. There is a need for POM research to address interrelated issues across organisations which are not well structured.

AR is a methodology for conducting empirical research and considering the emphasis that has lately been put on conducting empirical research in POM it can be said that AR is appropriate when the research question relates to describing an unfolding series of actions over time in a given group, community or organisation; understanding as a member of the group how and why their action can change or improve the working of some aspects of a system; and understanding the process of change or improvement in order to learn from it (Coghlan and Barnnick, 2001). Some of the characteristics summarised by Gummesson (2000) that make it a strong methodology for empirical research are:

a. Action researchers take action or in other words make it happen.

b. AR always involves two goals which is to solve a problem and contribute to science.

c. AR is interactive as it requires co-operation between researcher and members of the system under investigation.

d. AR aims to understand holistic understanding during a project and recognising complexity.

e. AR is fundamentally about change.

f. AR requires the understanding of ethical framework, values and norms within which it is used in a particular context.

g. AR can include all types of data gathering methods.

h. AR requires a breadth of pre-understanding of corporate environment, condition of business and the structure and dynamics of operating business.

i. AR can be conducted as a live case study as well as retrospective AR which is also acceptable.

j. AR requires its own quality criteria and should not be judged by criteria of positivist science but rather within the criteria of its own terms.

3.3.3 How AR?

The majority of AR projects are situation specific and they do not aim to generate universal knowledge. Therefore it becomes necessary to extrapolate to other situations and to identify how an AR project can benefit other organisations facing similar issues. A useful guide is provided by Eden and Huxham (1996) to show how AR contributes to theory:

a. AR generates emergent theory, in which the theory develops from a synthesis of that which emerges from the data and that which emerges from the use in practice of the body of theory which informed the intervention and research intention.

b. Theory building as a result of AR will be incremental moving from the particular to the general in small steps.

c. AR demands an explicit concern with theory that is formed from the conceptualisation of the particular experience in ways that are intended to be meaningful to others.

d. It is not enough to draw on the generality of AR through the design of tools, techniques and models as the basis for their design must be explicit and shown to be related to theory.

Action research does not have to justify when it is compared with alternative research approaches (Susman and Evered, 1978). AR can be justified within its own terms by the generation of an emergent theory based on data generation and data reflection during the research process (Schein, 1987; Eden and Huxham, 1996).

3.3.4 AR versus Consulting

One of the major concerns of AR is that it is often branded as a consultancy approach rather then a research methodology. Gummesson (2000) has answered this criticism and depicted four ways in which consultancy and AR are different:

a. Consultants who work in AR mode are required to be more rigorous in their inquiry and documentation.

b. Researchers require theoretical justifications whereas consultants require empirical justifications.

c. Consultants work under tighter time constraints.

d. Consultation is frequently linear engage, analyse, act and disengage. Whereas AR is cyclical in nature that requires gathering data, feeding it back, analysing data, planning action, taking action and evaluating, that leads to further data gathering and so on.

3.4 Research Design

Research design describes the research approaches necessary to undertake a study. The design is constructed on the grounds of research questions, research aims and research objectives (Robson, 2002). In order to carry out this research it was divided into two stages as shown in Figure 3.1. The two stages of this research are:

Stage 1: Development of a Technology Selection Framework

Stage 2: Operationalising the Developed Technology Selection Framework

The two research stages consisted of a number of activities (Figure 3.1) that have to be performed for the successful completion of that research phase. The research stages and the activities involved in each of the stage are explained in detail in the next section.

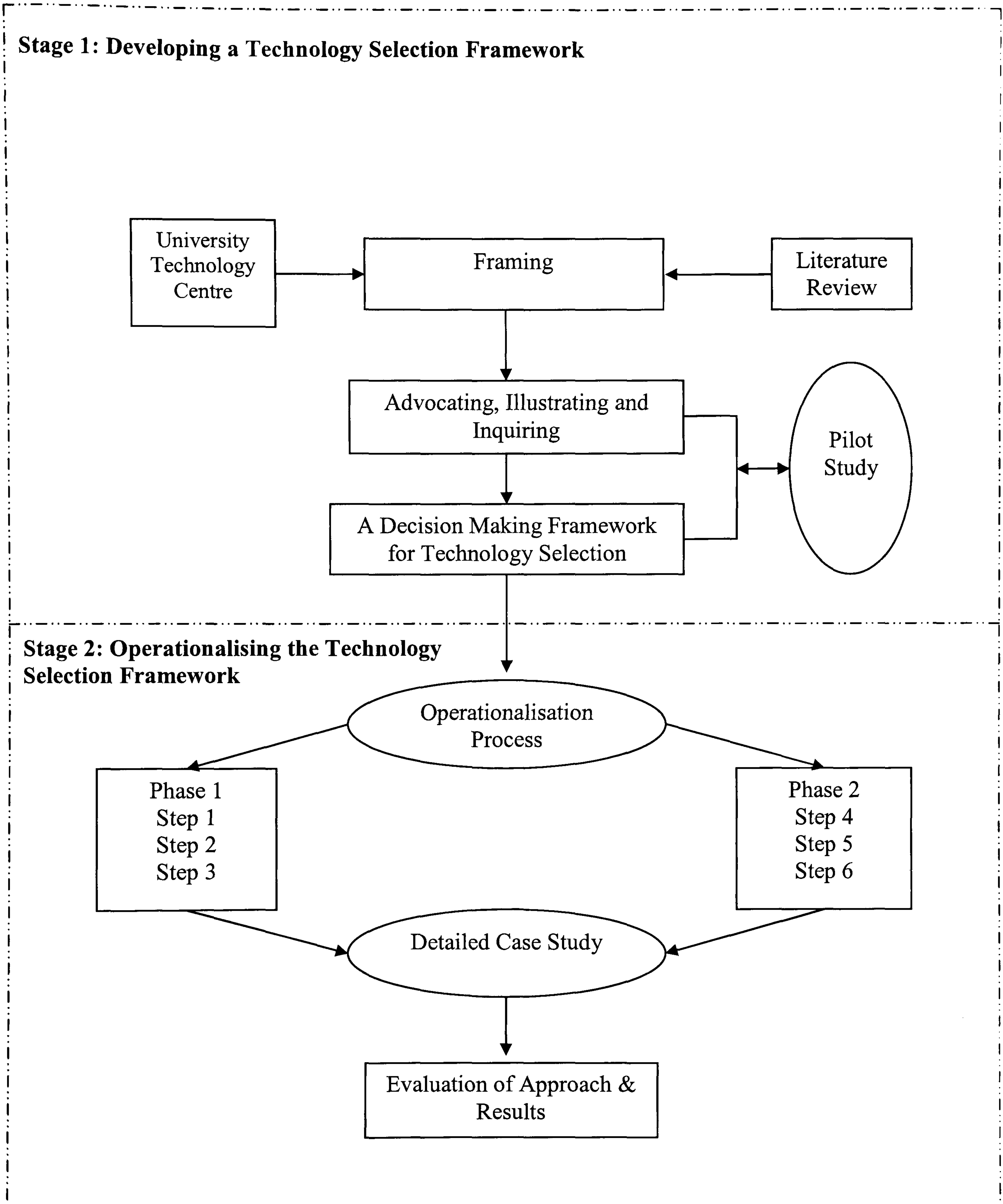

Figure 3.1: Research Process

3.5 Stage 1: Developing a Technology Selection Framework

The first stage of this research was about developing a technology selection framework. The technology selection framework development was carried out by contacting a company providing industrial automation solutions and an aerospace manufacturing company. The technology selection framework development stage consisted of the following activities:

3.5.1 Framing

Framing was about explicitly stating the purpose of the research and clarifying the research questions and the scope of the research. This activity was primarily carried out by investigating the literature on manufacturing strategy, technology selection and supply chain strategies. In order to understand the issues surrounding the research topic in more detail regular visits were made to a research group in the 'University of Nottingham' that was working on technology roadmapping for a renowned aerospace manufacturing company. By looking at the appropriate literature and latest research being carried out at the university research centre, it became clear the direction in which the academics and industry were heading with respect to technology selection and what could be the major concerns or point of interest for both industry as well as academics in the near future.

3.5.2 Advocating, Illustrating and Inquiring

Since one of the major aims of this research was to operationalise the developed technology selection framework in practice it was deemed necessary to involve the companies at a fairly early stage of the research. The purpose of this involvement was to have feed back from the companies at an earlier stage that can be incorporated into the decision making framework for technology selection. In this respect the first step was to actively advocate the research objectives and research contributions to the companies. A number of visit to the companies resulted in face to face discussions in which the researcher explained the rationale behind this research. A series of questions (Appendix

A) regarding the manufacturing business, supply chain activities and technology selection processes employed at the companies were asked to better understand the organisation. The next step was to illustrate the importance of this research by considering one of their products during the face to face meetings. Finally the companies were asked in the shape of semi- structured interview about their expectations of a technology selection process (Appendix B).

3.5.3 A Decision Making Framework for Technology Selection

The initial feedback from the companies combined with the literature review resulted in an initial technology selection framework. In order to gain feedback from the academic community the initial technology selection framework was presented in the 14^{th} Working Seminar of Production Economics 2006. Useful comments and suggestions given during the seminar from experienced and seasoned academics helped the researcher to re-evaluate and refine the initial framework. The refined technology selection framework comprising of six steps is described in detail in Chapter 4.

3.6 Stage 2: Operationalising the Technology Selection Framework

The second stage of the research was about operationalisation of the technology selection framework. The technology selection framework was first operationalised in the company providing industrial automation solutions on a pilot scale. After observing the applicability and sensitivities of different analytical tools employed in the technology selection framework it was operationalised in an aerospace manufacturing company in a detailed case study. The operationalising stage of the research consisted of the following activities:

3.6.1 Operationalising Process

The technology selection framework operationalisation process was conducted in two phases.

3.6.1.1 Operationalisation Phase 1

The first phase of operationalisation process consisted of three steps.

Step 1

The first step was about evaluating the current supply chain. A product was identified in each of the companies and then the importance and performance of several supply chain objectives of the product from the company perspective were evaluated using the questionnaire provided in Appendix C.

Step 2

The second step was to determine the critical supply chain factors on which the selected product in step 1 should be competing. This process was participatory in nature and involved the concerned supply chain managers to decide upon the factors that should be considered for market competition. The researcher acted as a facilitator by providing the insight into the importance and performance of several supply chain factors evaluated in the first step so that the managers can identify the critical factors.

Step 3

The third step was about determining the time horizon over which the selected product will be competing on the identified critical supply chain factors. The nature of this process was consultative and required the supply chain managers to reach a consensus regarding the time horizon for market competition.

3.6.1.2 Operationalisation Phase 2

The second phase of the operationalisation process consisted of a further three steps described below:

Step 4

The fourth step was the identification of manufacturing technologies to fulfil the supply chain factors. This involved the expertise of the technology mangers to brainstorm to identify the technologies that can fulfil the identified supply chain factors over a desired time horizon.

Step 5

The fifth step required detailed assessment of the identified technologies. This required the technology managers to identify the opportunities and threats that a technology presents not only in the manufacturing environment but also in a supply chain environment and general environment (explained in Chapter 4). The researcher helped the technology mangers to prioritise the identified technologies according to the opportunities and threats they presented using Expert Choice software (Analytical Hierarchy Process –AHP).

Step 6

The final step was the risk assessment of the identified technologies. It required the technology mangers to identify the probability of occurrence of a particular opportunity or threat associated with a technology alternative (Appendix D). They were also required to provide the risk aversion factor for each technology opportunity and threat.

3.6.2 Evaluation of Approach and Results

The main criteria for any process evaluation are feasibility, usability and utility (Platts, 1994). The feasibility of this process was judged by the application of the technology selection framework in a pilot study and then later in a detailed case study. In the detailed case study the technology selection framework was used to evaluate technologies for seven engine components to comprehensively evaluate the feasibility of its application.

The utility of the process and usability of the process were examined by the help of questionnaire (Appendix E) that was distributed to the participating technology managers. The evaluation of the results for the technology selection was based on a number of techniques including the analytical hierarchy process, utility theory and entropy concepts that all constituted the decision making process for the technology selection.

3.7 Reliability and Validity

Action research does not have to justify itself in relation to alternative epistemologies and research approaches (Susman and Evered, 1978). The challenge for an action researcher is to define and meet standards of appropriate rigour without sacrificing relevance. The fact that action research is non traditional in POM does not excuse it from the rigour of traditional approaches (Westbrook, 1995). AR does not have any specific criteria for reliability and validity as compared to quantitative (survey based) and traditional qualitative (case study) approaches. However an approach called triangulation that combines several research methodologies to study the same phenomenon and which is an alternative to traditional criteria such as validity and reliability (Jack and Raturi, 2006; Mangan et al., 2004) is widely popular among researchers. The most important and attractive attribute of triangulation is to provide completeness to a study (Jack and Raturi, 2006) which resulted in adopting it as an alternative to traditional reliability and validity criteria's.

3.7.1 Triangulation

Triangulation is the use of multiple measures and methods to overcome the inherent weakness of single measurement instruments (Denzin, 1970). Use of different research approaches, methods and techniques in same study can overcome the potential bias and sterility of single method approaches (Hussey and Hussey, 1997). Four different types of triangulation have been identified by Easter-Smith et al. (1997) which are:

a. Data Triangulation, where data is collected at different times or from different sources

b. Investigator Triangulation, where different investigators independently collect data

c. Methodological Triangulation, where both qualitative and quantitative techniques are employed

d. Triangulation of Theories, where a theory is taken from one discipline and used to explain a phenomenon in another discipline

This research has benefited from different types of identified triangulation in the following ways:

a. Data Triangulation

Data triangulation was achieved by collecting data from different technology managers during different times. Moreover the data collection techniques involved onsite interviews, observations and facilitation of the researcher to the technology managers to prioritise the technology alternatives using Expert Choice Software (AHP) which converts the qualitative judgements into quantifiable numerical scores.

b. Methodical Triangulation

Methodical triangulation in this research consisted of different qualitative and quantitative techniques. Qualitative methods included semi-structured interviews, brainstorming sessions and questionnaires. Quantitative methods included use of AHP and a mathematical model for risk calculation.

c. Triangulation of Theories

The concept of entropy was employed in the mathematical model (detail in Chapter 4) used for the risk calculation associated with each technology alternative. Entropy is one of the factors that determines the free energy in the system and appears in the second law of thermodynamics. In terms of statistical mechanics the entropy describes the number of the possible microscopic configurations of the system. The statistical definition of entropy is generally thought to be the more fundamental definition, from which all other important properties of entropy follow. Although the concept of entropy was originally a thermodynamic construct, it has been adapted in other fields of study, including information theory, economics and evolution.

3.8 Conclusion

The aim of AR is to make the action more effective while simultaneously building up a body of scientific knowledge. AR is combination of sequence of events and approach to problem solving. AR involves iterative cycles of gathering data, feeding them back to those concerned, analysing data, planning action, taking action and evaluating leading to further data gathering. In short AR is an application of the scientific method of fact finding and experimentation to practical problems requiring action solutions and involving the collaboration of the action researcher and members of an organisational system. The output of an AR approach is not only a solution to immediate problems but is an important learning from outcomes both intended and unintended and a contribution to scientific knowledge and theory (Coughlan and Coghlan, 2002).

The nature of this study and the objectives associated with it lead to AR as the selected research methodology. The actual research process was divided into two stages and each of the two stages consisted of several sub activities that were carried out for the successful completion of each stage. The next chapter will introduce the technology selection framework and will provide a detailed working of the framework with its application to a pilot case study.

Chapter 4

Technology Selection Framework

4.1 Introduction

This chapter presents the technology selection framework developed by examining the current available technology selection processes in the literature described in detail in Chapter 2. The chapter explains all the steps involved in the technology selection framework and the tools and techniques employed in the technology selection process are also elaborated in detail. A pilot case is then presented which evaluated the practical applicability of the technology selection framework in an industrial scenario.

4.2 Technology Selection Framework

The concept of manufacturing strategy remains important to both researchers and industrial managers as companies enter the next millennium. Recently the creation of formalised supply chains intended to provide their members with strategic advantages has provided an additional challenge to the formulation of sound manufacturing strategies (Lockamy, 2004). In a supply chain a firm is not supposed to develop a manufacturing strategy that is only internally consistent with their corporate and business unit strategy but they are expected to develop a supply chain strategy which will provide all supply chain trading partners with economic benefits. The most elementary step in this respect is to align the manufacturing and supply chain objectives. The first step towards this purpose is to integrate supply chain and manufacturing in a single decision making loop. Manufacturing companies are putting a lot of effort into improving their internal operations by acquiring advanced manufacturing practices, and although the manufacturing practices and their relationship with performance have been widely studied the relationship between supply chain integration and manufacturing improvement programmes has been rather neglected (Cagliano et al., 2006).

A framework for technology selection is proposed considering the role and significance of advanced technology as enablers of manufacturing and supply chain strategy. The proposed framework is inspired from already available technology selection frameworks in the literature and aims to develop a simple and efficient decision making framework which is easy to understand, covers all areas regarding technology selection and can be readily applicable in any type of industry. This framework combines supply chain and manufacturing together to achieve the business objective. This framework takes into account not only the views of the experts and managers of the company but also gives due consideration to the capabilities and requirements of the other supply partners. This helps in understanding the dynamics of the supply chain which simplifies the process of making the correct decision for technology selection that is best not only for the company but is also in the interest of the supply chain.

A technology selection framework that incorporates manufacturing and supply chain objectives in a single decision making framework is presented. The framework for manufacturing technology selection consists of six steps. The steps are systematically linked to each other as shown in the figure 4.1 and named below:

- Evaluation of Current Supply Chain
- Critical Supply Chain Factors for Competition
- Planning Range/Time Horizon
- Identification of Manufacturing Technology
- Detailed Assessment of Identified Technology
- Risk Assessment of Technology Alternatives

4.2.1 Evaluation of Current Supply Chain

Step 1 of this framework is to evaluate the current supply chain performance of a product for which there are more than one technology alternatives available. The main attribute of step 1 is the involvement of the relevant company managers in evaluating their own supply chain which gives them a first hand picture about their performance as compared to the market needs and demands and directs them towards their strong and weak links in order to sustain the increasing pressure from their competitors. This leads to the re-evaluation of their business strategy and provides them with an indication of into which areas they need to put in more effort and the areas where they are doing better than their competitors.

Maskell (1991) suggests that types of performance measures required for a manufacturing organisation are directly related to the manufacturing strategy chosen by the company. The reasons for establishing this relationship is to judge whether the performance of a company is meeting its strategic goals and secondly people in the organisation will concentrate on what is measured, thus performance measures will steer company direction. Several supply chain performance metrics will be used from the existing literature to determine the performance. 'Cost' is the most predominantly used supply chain performance measure (Cohen and Lee, 1988; Cohen and Moon, 1990; Lee and Feitzinger, 1995; Ghodsypour and O'Brien, 1998). Therefore cost is introduced as the first supply chain performance measure. Although cost is the most familiar competitive dimension, it is not the only basis on which a business competes. In some businesses the basis of competitive advantage is superior quality, achieved either by higher product reliability or by manufacturing a product with features or capabilities that are unavailable in competing products. The cost of providing higher quality can be negated by markets willingness to pay for the high quality product. The nature of this balance has power implications for the role of manufacturing in the business (Hayes and Wheelwright, 1984; Mapes et al., 1997; Slack et al., 1995). Bearing in mind the importance of 'Quality' it is introduced as the second supply chain performance measure. Since product life cycles have shrunk considerably and rapid development of new products has caused greater competition among companies to capture market share this has resulted in the ever increasing importance of shorter lead times (Cook and Rogowski, 1996; Christy and Grout, 1994; Davis, 1993; Kengpol and O'Brien, 2001). 'Lead time' is therefore the third supply chain performance measure that is introduced for evaluation. 'Flexibility' is another supply chain factor on which they compete and is critical for their success. Flexibility can mean to meet the individual demands of the customers. Some flexibility measures include machine/tool set up time, economies of scope and number of inventory turns (Gunasekaran et al., 2004). This is the reason flexibility is introduced as the next supply chain performance measure to be evaluated in this process. The market life span of products is decreasing and their rate of development is predicted to double every five years. Thus the production of a steady stream of new products that customers will desire and appreciate is a key factor in maintaining and improving competitive advantage (Barclay et al., 2000). Recognising the importance of 'New Product Development' (NPD) as a concept that can provide strategic advantage it is included as the final performance evaluation measure of the supply chain.

Use of the importance performance matrix developed by Slack (1994) is proposed for the evaluation process. The importance-performance matrix is supposed to help in setting the priorities. The importance- performance matrix is used in this process to observe the performance of the supply chain compared to its competitors with reference to a particular performance metric like cost, quality, lead time, flexibility and new product development and the importance of that particular performance metric in the current supply chain. The results obtained are plotted on the importance performance scale depicting the true picture of the supply chain.

4.2.2 Critical Supply Chain Factors for Competition

Step 2 is the clear identification of the critical factors on which a supply chain plans to compete. Once the strength and weaknesses of the supply chain are indicated the next step is to select a few factors from the indicated factors for re-defining the business strategy according to the market condition. The major outputs from this step are the identification of the core competencies, defined as a set of factors for market competition and re-defined business strategy.

4.2.3 Time Horizon

Step 3 is to define the planning range for the supply chain to compete on the factors defined in the second step. The supply chain members may wish to compete on a long, medium or short term basis. The major input is the re-defined business strategy that is the product of the second step described above. Another input is the nature of the market and business in which the supply chain is planning to compete. The major output of this step will be the future vision of the business and the supply chain. The other output will be the requirement of the means and definition of resource allocation to execute the proposed actions.

4.2.4 Identification of Manufacturing Technologies

Step 4 in the framework is to identify the suitable manufacturing technologies to fulfil the critical supply chain objectives defined in the second step. This involves the input of a technology scanning process and requires carefully selected experts who understand the technical conformance expected from the selected technology.

4.2.5 Detailed Assessment of Identified Technologies

Step 5 is the detailed assessment of the identified technologies. A review of the literature shows the availability of various techniques for multi-criteria decision making such as ranking of alternatives, scoring models, utility models, fuzzy techniques, analytical hierarchy process and multi objective mathematical programming techniques such as goal programming. This framework makes use of the analytical hierarchy process (AHP) developed by Saaty (1980) and the strategic assessment model (SAM) presented by Tavana and Banerjee (1995). In this step there is an effort to bridge the gap between the business objectives and the manufacturing capabilities of the supply chain. This has been done by dividing the decision making environment into manufacturing, supply chain and general environment and by determining the probability of occurrence of the opportunities and threats associated with each technology alternative in three different decision making environments. This enables the selected experts to visualise the technology assessment from a wider supply chain perspective. The output of the process is the identification of possible technologies to achieve manufacturing and supply chain goals and the detailed characteristics of each available technology alternative.

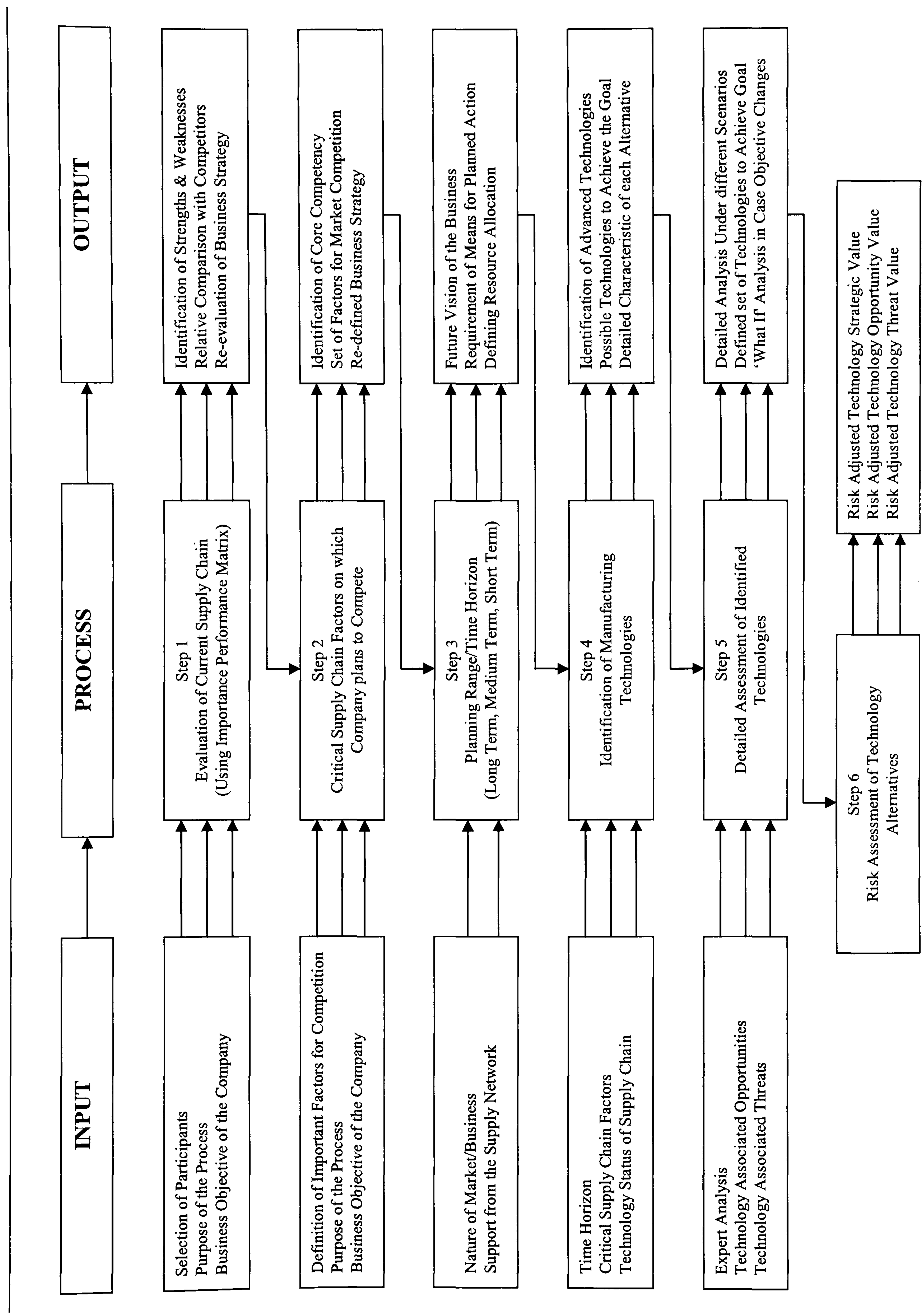

Fig 4.1: Proposed Technology Selection Framework

4.2.6 Risk Assessment of Technology Alternatives

The final step is the risk assessment of the identified technologies in which the risk associated with each technology alternative in terms of opportunity and threat is evaluated before selection. The output of this step is the overall risk adjusted technology strategic value which is the algebraic sum of risk adjusted technology opportunity value and risk adjusted technology threat value.

4.3 Use of AHP in the Technology Selection Framework

Multi-criteria decision making (MCDM) is a discipline to provide support to decision makers who are faced with making numerous and conflicting evaluations. The multi criteria decision making process aims to highlight different conflicts in the decision making process and provide a transparent and systematic approach to compromise with these conflicts. A number of tools are available for the multi-criteria decision making process and are used by researchers according to needs and demands of a research project and also according to the comfort levels and familiarity of the decision maker. In this research the 'Analytical Hierarchy Process' (AHP) is preferred over other available multi-criteria tools because of its usability in the 'Strategic Assessment Model' (SAM) for the determination of technology risk adjusted strategic values.

The 'Analytical Hierarchy Process' (AHP) is a problem-solving framework and a systematic procedure for representing the elements of any problem (Saaty, 1982). According to Saaty the use of AHP allows for the rational evaluation of pros and cons associated with the multiple criteria decision making environment. AHP is a theory of measurement for dealing with quantifiable and intangible criteria's that have been applied to various decision making areas (Vargas, 1990). The AHP approach consists of the following main steps namely:

- Decomposition
- Comparative Judgement

- Synthesis of Priorities
- Sensitivity Analysis

The AHP process starts by decomposing a complex multi-criteria problem into a hierarchy where each level contains few well defined elements which are then decomposed into another set of elements. Comparative judgement is the process to establish priorities among elements defined at each level of hierarchy and is carried out using the table 4.1. Finally the synthesis of the priorities developed at each level establishes the overall priorities for the decision alternatives.

Intensity of Importance on an Absolute Scale	Definition	Meaning
1	Equally important	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgement moderately favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Extremely important	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	When compromise is needed

Table 4.1: AHP Pairwise Judgement Table Developed by Saaty

In AHP, sensitivity analysis of the outcome is carried out to determine the stability of the best outcome against 'what if' type of change in the priorities of the criteria. In order to ascertain the errors committed by the decision makers in the pairwise hierarchies the AHP Expert Choice Software contains an inbuilt function to calculate the consistency ratio. If the value of the consistency ratio is less then 0.10 the results are deemed to be acceptable as it shows that there have been few discrepancies regarding the prioritisation of different elements in the hierarchies and most of the decisions were consistent and coherent. The AHP properties can be summarised according to Dyer and Forman (1992):

- Tangible/Intangible values can be included
- Individual and shared values can included
- Discussion can be focussed on goal or alternatives
- Structured discussion providing comprehensive analysis of each factor

4.4 Use of SAM in Technology Selection Framework

The technology selection processes, methodologies and techniques presented in the literature as described in Chapter 2 have been found short of any sort of risk assessment of the available technology alternatives for the technology selection process. The literature has been advocating the role of risk associated with technology alternatives but presented no means of risk evaluation. Keeping in view the importance of risk evaluation in the technology selection process, the technology selection framework developed incorporates the 'Strategic Assessment Model' presented by Tavana and Banerjee (1995) in the existing framework. The SAM provides the facility to calculate the risk associated with each technology alternative in terms of opportunities and threats. Therefore the risk calculations provide a greater level of analytical comprehensiveness to the technology selection process. A number of different analytical techniques and concepts are used in SAM to supplement managerial intuition, knowledge and judgement. One of the major applications of SAM has been in NASA for evaluating and prioritising advanced technology projects (Tavana, 2003). In the following sections all the steps included in the SAM are discussed.

4.4.1 Step 1

The first step in the SAM is the generation of alternatives. Alternatives are the means by which the desired objectives are attained. In order to successfully implement the process there must be at least two mutually exclusive alternatives.

4.4.2 Step 2

The next step is the identification of opportunities and threats associated with generated alternatives. In this research the opportunities and threats associated with identified technology alternatives were categorised into manufacturing, supply chain and general environment. The manufacturing environment considers the intra-organisational whereas the supply chain environment considers the inter-organisational opportunities and threats associated with the identified technology alternatives.

4.4.3 Step 3

SAM uses AHP for determining the relative importance of manufacturing, supply chain and general environment. Similarly AHP is used to determine the environmental weights for the opportunities and threat factors.

4.4.4 Step 4

The next step is the calculation of initial weights associated with the opportunities and threats. Once again AHP is employed for the pairwise comparison of factors within each defined environment.

4.4.5 Step 5

The subjective probability of the occurrence of each opportunity and threat for each alternative is determined in this step. The subjective probability can be measured by asking the decision maker for odds on an event. It is assumed in SAM that the subjective probability of realising a situation is binomial. Binomial probabilities are commonly used in strategic decision making as the decision maker can simplify the problem by analysing the possible outcomes as either occurring or not occurring.

4.4.6 Step 6

The overall importance weight for opportunities and threats is considered next in SAM. The overall importance weight of an opportunity is directly related to the intrinsic weight, reflecting average intrinsic information developed by a set of alternatives and the subjective weight reflecting the subjective assessment of its importance given by a decision maker. The probabilities of occurrence are used to measure the average intrinsic information.

4.4.7 Step 7

The next step is to consider the decision maker risk aversion constant for the opportunities and threats. Certainty equivalence (C.E) is employed to calculate the risk aversion constant by assuming a lottery where 1 represents the occurrence and 0 represents the non occurrence of an opportunity or threat. According to the certainty equivalence method C.E=0 represents complete risk aversion meaning an infinite value of the risk aversion constant (r). Whereas C.E= 0.50 means complete risk neutrality with r= 0. The value of the risk aversion constant is determined by equating the utility of an exponential function and the utility of the certainty equivalence (Appendix I). An exponential utility function is used for this purpose as it is the simplest model of risk aversion.

4.4.8 Step 8

The final step is the calculation of the risk adjusted strategic value for each technology alternative. The overall technology strategic value is the sum of risk adjusted opportunity value and the risk adjusted threat value. Thus the final selected alternative is selected after the risk associated with all the alternatives in terms of opportunities and threats in the three different decision making environments has been evaluated.

4.4.9 SAM Algebraic Model

The steps defined above are represented in the form of an algebraic model in the SAM for the calculation of risk adjusted strategic technology alternative. A solvable approach for the algebraic model developed by Tavana and Banerjee (1995) is described below.

The following equation (1) is used for determining the overall importance weight of an opportunity.

$$\hat{F}_{uij} = \frac{F_{uij}.w_{uij}}{\sum_{j=1}^{N_{ui}} F_{uij}.w_{uij}} \quad .... (1)$$

Where

$\hat{F}_{uij}$ = Overall Importance Weight for the jth Opportunity Factor in the ith Environment

F_{uij} = Intrinsic Weight for the jth Opportunity Factor in the ith Environment

w_{uij} = Initial Weight Associated for the jth Opportunity Factor in the ith Environment

In the above equation (1) the initial weight associated with opportunities (w_{uij}) is determined by using the method described in section 4.4.4. The intrinsic weight of an opportunity (F_{uij}) is determined by using the following equation (2).

$$F_{uij} = \frac{1}{N_{ui} - E}[1 - e(p_{uij})] \quad .... (2)$$

Where

F_{uij} = Intrinsic Weight for the jth Opportunity Factor in the ith Environment

N_{ui} = Number of Opportunity Factors in the ith Environment

E = Total Entropy

In the above equation (2) the total entropy (E) is calculated by using equation (3).

$$E = \sum_{j=1}^{Nui} e(p_{uij}) \quad .... (3)$$

Where

E = Total Entropy

N_{ui} = Number of Opportunity Factors in the ith Environment

$e(p_{uij})$ = Entropy Measure of jth Opportunity Factor in the ith Environment

In the above equation the entropy measure ' $e(p_{uij})$ ' is calculated by using equation (4).

$$e(p_{uij}) = -K \sum_{m=1}^{q} \frac{p_{uij}^{m}}{P_{ij}} \ln \frac{p_{uij}^{m}}{P_{ij}} \quad .... (4)$$

Where

$e(p_{uij})$ = Entropy Measure of the jth Opportunity Factor in the ith Environment

q = Total Number of Alternatives

K = 1/lnq

p_{uij}^{m} = The mth Probability of Occurrence of the jth Opportunity Factor in the ith Environment

P_{ij} = Sum of Probability of Occurrences of the jth Opportunity Factor in the ith Environment

Considering the three decision making environments for i=1 through 3 representing manufacturing, supply chain and general environments respectively the risk adjusted strategic value for the mth strategic technology alternative is given by equation (5).

$$V^{m} = U^{m} + T^{m} \quad .... (5)$$

Where

V^{m} = Total Weighted Risk Adjusted Strategic Value of the mth Alternative

U^{m} = Total Weighted Risk Adjusted Opportunity Value of the mth Alternative

T^{m} = Total Weighted Risk Adjusted Threat Value of the mth Alternative

In equation (5) the risk adjusted opportunity value (U^m) and the risk adjusted threat value (T^m) can be determined by using equation (6) and equation (7).

$$U^m = \sum_{i=1}^{3} W_{ui}[\sum_{j=1}^{Nui} \hat{F}_{uij}\{\frac{-1}{r_{uij}}\ln(1 - p_{uij}^m + p_{uij}^m e^{-r_{uij}})\}] \quad \ldots\ldots\ldots (6)$$

Where

U^m = Total Weighted Risk Adjusted Opportunity Value of the mth Alternative

W_{ui} = The ith Environment Weight for Opportunity

N_{ui} = Number of Opportunity Factors in the ith Environment

$\hat{F}_{uij}$ = Overall Importance Weight for the jth Opportunity Factor in the ith Environment

r_{uij} = Risk Aversion Constant for the jth Opportunity Factor in the ith Environment

p_{uij}^m = The mth Probability of Occurrence of the jth Opportunity Factor in the ith Environment

In the above equation (6) the environment weight for opportunity (W_{ui}) is calculated by using the method described in section 4.4.3. Similarly the risk aversion constant (r_{uij}) for opportunities is determined by the process described in section 4.4.7.

$$T^m = \sum_{t=1}^{3} W_{ti}[\sum_{j=1}^{Nti} \hat{F}_{tij}\{\frac{-1}{r_{tij}}\ln(1 - p_{tij}^m + p_{tij}^m e^{r_{tij}})\}] \quad \ldots\ldots\ldots (7)$$

Where

T^m = Total Weighted Risk Adjusted Threat Value of the mth Alternative

W_{ti} = The ith Environment Weight for Threat

N_{ti} = Number of Threat Factors in ith Environment

$\hat{F}_{tij}$ = Overall Importance Weight for the jth Threat Factor in the ith Environment

r_{tij} = Risk Aversion Constant for the jth Threat Factor in the ith Environment

p_{tij}^m = The mth Probability of Occurrence of the jth Threat Factor in the ith Environment

The procedure for the calculations of the risk adjusted threat value using the equation (7) is similar to the one described above for the risk adjusted opportunity value. The only difference is that in all the equations for the opportunity value calculations the opportunity factors are replaced by the factors representing threat values.

4.5 Pilot Study

In order to observe the functionalities of the technology selection framework and to determine the industrial applicability of the technology selection process it was decided to implement the technology selection framework in an industrial setup where technology selection decision making was an area of concern for the technology selection manager.

4.5.1 Case Study "A Bag in Box"

One of Europe's largest producers of recycled paper and corrugated packaging presents "Bag in Box" as a packaging solution that combines the advantages of cardboard with a plastic bag interior. The products lightweight design offers high stacking strength and is suitable for various applications such as cooking oils or any other liquid. As a part of the product offer, the company wanted to supply its customers not only with packaging material but also with case erecting and bag insertion machinery. Therefore a machine was required for obtaining consistently high quality and accuracy in placing and securing the folded bag into the erected box and then expanding the inserted bag for filling. The packaging company contacted an industrial outfit that provided innovative automation machinery and automated production systems for the automotive, food & drink, consumer goods and general manufacturing industries. The technology selection framework presented in this chapter was used to determine the best technology alternative for placing the folded bag into the erected box.

The importance and performance of various supply chain objectives for "Bag in Box" assembly were determined by using the questionnaire provided in Appendix C and figure

4.2 shows the importance-performance diagram. The company manager dealing with the supply chain was involved in the evaluation process.

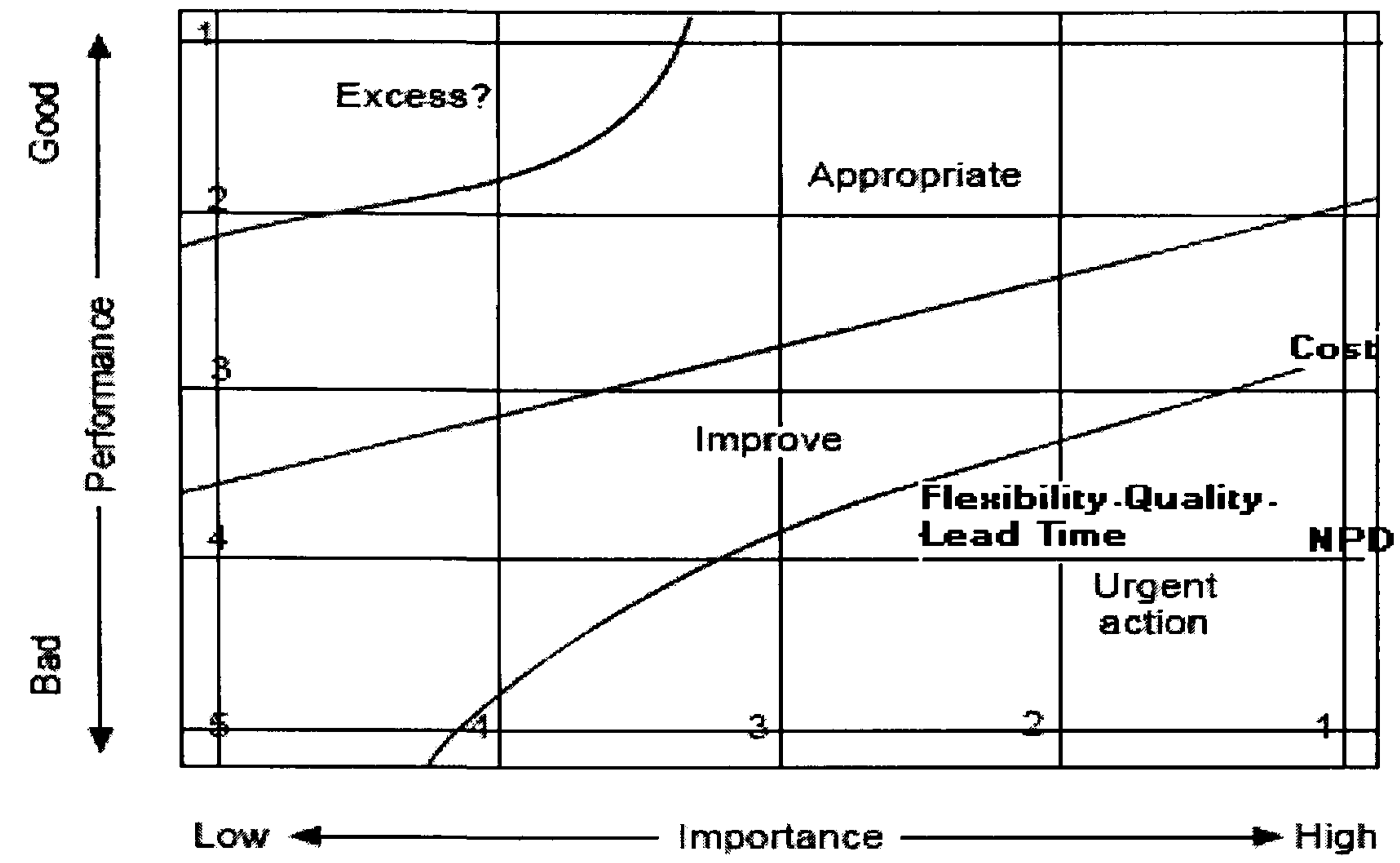

Figure 4.2: Bag in Box Importance Performance for Supply Chain Objectives

It is clear from the above graph that cost and new product development (NPD) are prioritised as very important by the company and the performance of the supplier in satisfying these performance objective is good for cost placing it in the improvement zone on the above graph and satisfactory for NPD which makes it fall in the region of urgent action on the above graph. This means cost needs to be improved to stay competitive and the performance of the supplier in achieving NPD needs urgent action if the company plans to prioritise NPD as a highly important supply chain performance objective. Similarly lead time, flexibility and quality falls into the urgent action zone in the graph and needs to be looked at immediately.

The market evaluation of "Bag in Box" was done by using the same questionnaire provided in Appendix C. Figure 4.3 shows the market evaluation of "Bag in Box" assembly. Looking at figure 4.3 it can be easily seen that cost falls in the urgent action zone meaning that it is highly desirable in the market but the performance of the company in achieving it is below the industry standard or less than to compete with other competitors. Whereas lead time, quality, flexibility and new product development (NPD) are placed in the appropriate zone meaning the performance of the company in achieving these objectives is considerably better than the nearest competitor.

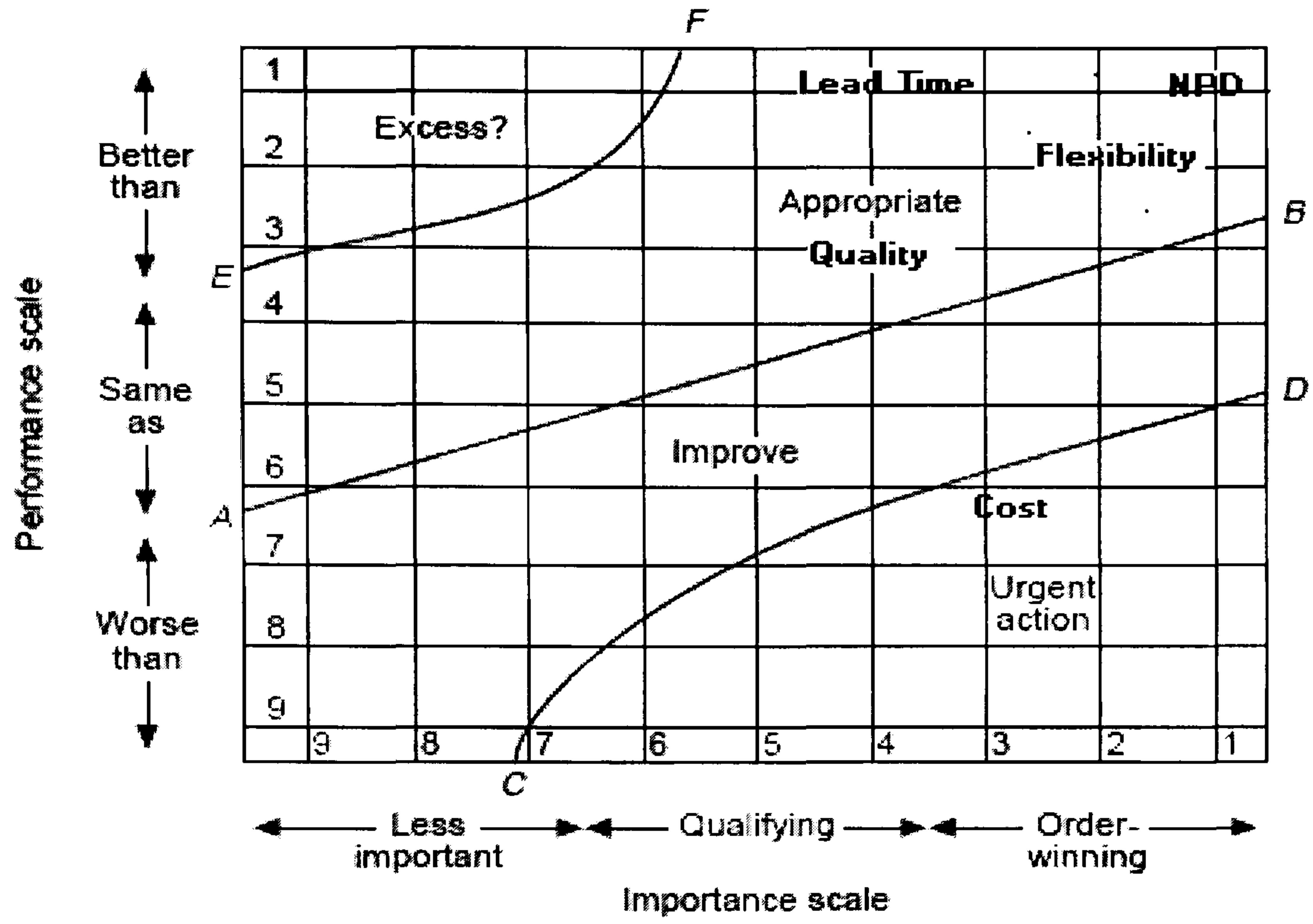

Figure 4.3: Bag in Box Market Evaluation

Three different manufacturing technologies were identified for "Bag in Box" assembly classified as:

- Robot Based Technology (Highly Flexible/Automated)
- Server Driven Flexible Technology (Moderately Flexible)
- Existing Technology (Low Flexibility)

The opportunities and threats associated with each technology alternative identified were brainstormed with the technology manager and classified into manufacturing, supply chain and general decision making environments as shown in figure 4.4 & 4.5. The probability of occurrence of each opportunity and threat associated with each technology alternative in each decision making environment was determined. The risk aversion factor for each opportunity and threat was also calculated and documented. Pairwise comparison was determined between different opportunities and threats in three different decision making environments. It is the input to the strategic assessment model (SAM) employed in the technology selection framework to determine the risk adjusted strategic value for different technology alternatives. The overall risk adjusted strategic value for each technology alternative calculated by this method is described in table 4.2. The detailed results are presented in Appendix G.

Risk Adjusted Strategic Value for Robot Based Technology	0.336
Risk Adjusted Strategic Value Server Driven Flexible Technology	0.391
Risk Adjusted Strategic Value for Existing Technology	0.007

Table 4.2: Risk Adjusted Strategic Value for Technology Alternatives

From table 4.2 it is clear that server driven flexible technology is the best technology alternative for bag in box technology when the risk associated with each of the identified technology alternatives is considered.

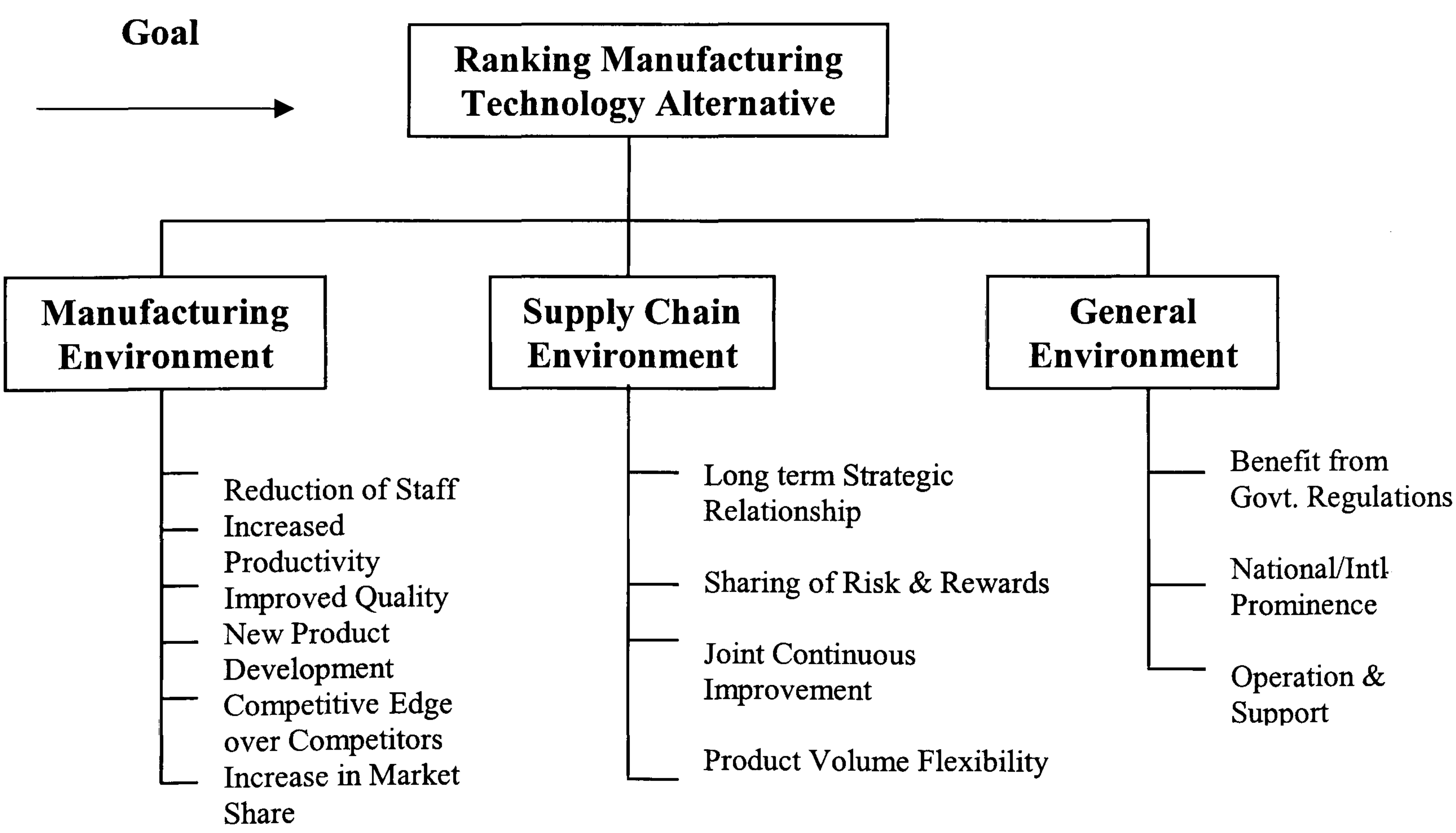

Figure 4.4: AHP Bag in Box Hierarchy (Opportunities)

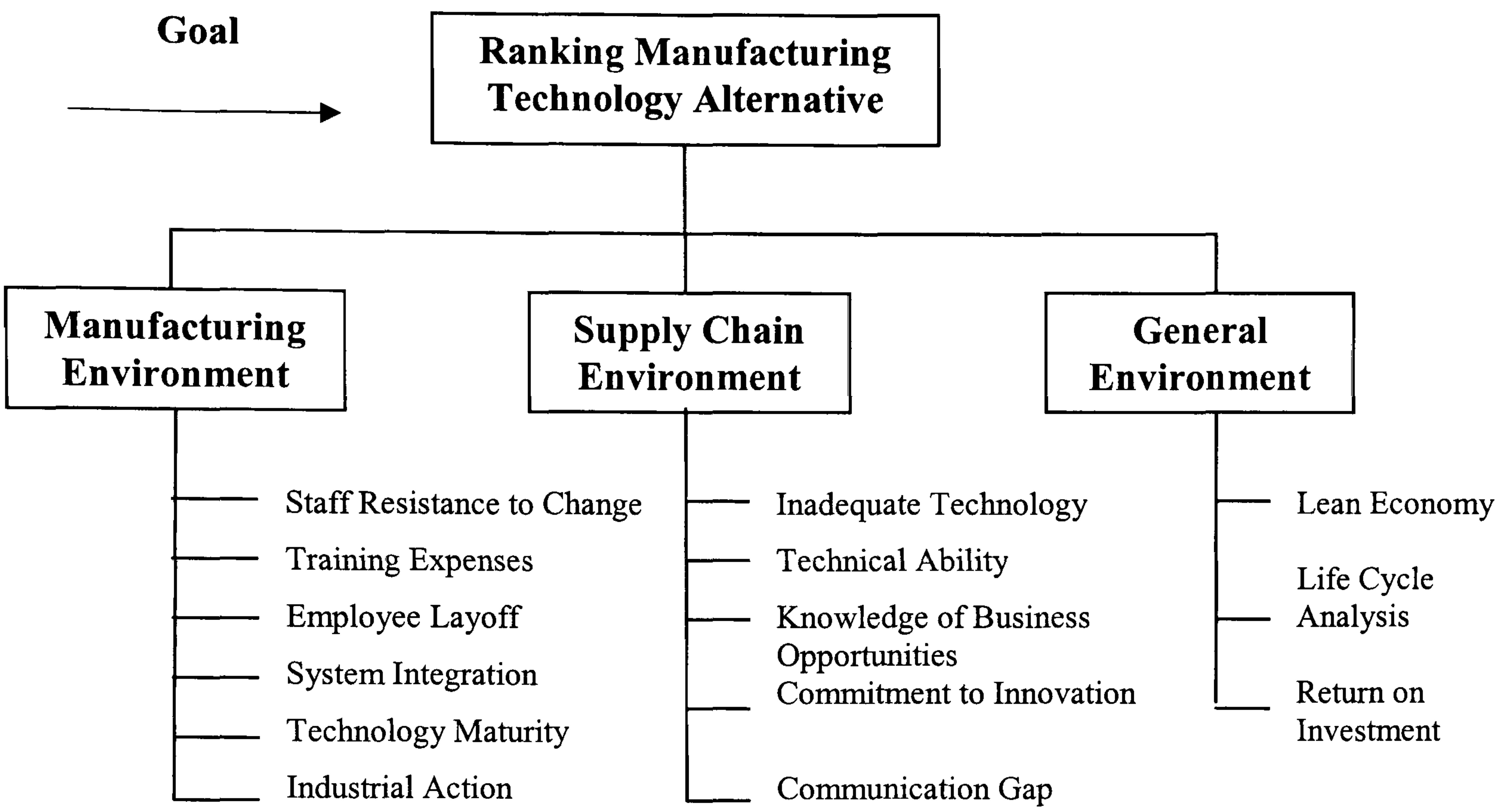

Figure 4.5: AHP Bag in Box Hierarchy (Threats)

4.6 Conclusion

The implementation of the technology selection framework in the industry on a pilot scale helped in providing insight into the working of the proposed framework. The most basic aspect that was highlighted was to have the same understanding of different supply chain performance measures by all the people involved in the supply chain evaluation process. Similarly it was very important to have the common understanding of the brainstormed opportunities and threats in the three different decision making environments. Therefore in the detailed case study as described in Chapter 5 it was decided to have individual as well as group sessions with supply chain and technology managers so that everyone agreed on the same definitions. The concept of considering supply chain factors while selecting technology was new to the technology mangers and therefore they were hesitant at start with the evaluation process. It was deemed necessary in future to be able to relate the technology selection process considering the supply chain functionally as well as holistically to the organisational business goals. In order to engage the technology managers in the technology selection process keeping in view the supply chain perspective it was thought to present them with the broader picture of their technology selection implications. It was noted that the SAM model used for risk calculations was sensitive to high threats value. Meaning if the technology mangers associated high threats values to a technology alternative compared to its opportunity value there is a fundamental mistake in considering that technology alternative in the first place. Clearly when a technology alternative offers more threats then opportunities it is no more a realistic alternative and thus should not be included in the technology selection process. During the implementation of the technology selection process it was noted that the technology managers found it difficult at first to understand the process of allocation of risk aversion factors to different opportunities and threats associated with each technology alternative. The risk aversion calculations required the process to be explained a number of times. This gave an indication to be clearer about risk aversion calculations in the detailed case study. In short the pilot case study helped in evaluating the technology selection framework in an industrial setup on a smaller scale. This provided an ideal opportunity to test the practical applicability of the framework and to improve the methods of data collection for the detailed case study as the success of the technology selection framework depends upon the human input of the supply chain and technology managers involved in the process. Therefore it was necessary to maintain the interest of all involved in the technology selection process by actively engaging the members by educating them about the technology selection framework and being educated by them about their manufacturing and supply chain practices.

This chapter has presented in detail the technology selection process developed. The tools, techniques and models employed in the technology selection framework are discussed in detail. A pilot case study is presented where the application of the technology selection framework was tested. The next chapter introduces the detailed case study and describes the implementation of the technology selection framework in an aerospace manufacturer.

Chapter 5

Case Study

5.1 Introduction

This chapter explains the application of the technology selection framework developed in the Chapter 4 in an industrial environment. This required the help and co-ordination of a company where technology selection plays a critical role in achieving their business success. Considering in mind the role of technology in the success of a company an aerospace manufacturer was contacted for this study and they after understanding the philosophy of this project collaborated actively as the outcome of this project gave them some directions towards their own defined future operational excellence goals.

5.2 The Technology Selection Framework and Aerospace Manufacturer

Aerospace is a specialised technology oriented industry where technology is synonymous with the performance of the product. Each and every aerospace product has a special set of technologies available for its manufacturing. Since safety is critical for aerospace products this emphasises a quality finish of the manufactured products to the highest industry standards. In achieving these competitive performance requirements new and advanced manufacturing technologies provide the needed leverage to attain the high industry standards. Therefore the aerospace sector is heavily dependent on manufacturing technologies for their successful operations.

For the above reasons the aerospace sector was deemed to be particularly suitable for the industrial implementation of the technology selection framework developed. There were various manufacturing technologies available for selection for different engine components. This provided an opportunity to look at the technology selection decisions in the company in detail by considering different engine components and technologies associated with these components. It provided an insight into how decisions were made regarding different manufacturing technologies in different decision making environments i.e. manufacturing, supply chain and general. Furthermore the role of opportunities and threats associated with each technology alternative in strategic technology selection was also examined and is described in detail in Chapter 6. In short the aerospace company provided an ideal platform to operationalise the technology selection framework and to observe in detail various aspects associated with the technology selection process in the aerospace company in general and with the developed technology selection framework in particular.

The process of the study in the aerospace company started from October 2005 after the initial development of the technology selection framework. It started with the initial presentations regarding the concept behind the framework and the main objectives and contributions of this study. The technology selection framework was refined over the course of this study as more understanding was developed regarding the issues surrounding the technology selection process. Moreover the feedback of the technology managers at the company provided a collaborative environment that helped in visualising the current technology selection process in the company. After refining and improving the initial technology selection framework and identifying the technologies and different engine components for technology selection regular workshops including brainstorming sessions for identifying the opportunities and threats associated with technology alternatives, AHP ranking of technologies and application of SAM were carried out during July 2006- March 2007. The company was re-visited in June 2007 after final computation of technology selection results to establish the foundations for a holistic application of this study within the company. The results of this study confirms the industry trends in the technology selection process as the majority of aerospace manufactures are moving from traditional manufacturing technologies towards manufacturing technologies that support lean manufacturing principles. There are a number of manufacturing technologies available conforming with lean principles thus again making a case for availability of tools, techniques and frameworks for the appropriate selection of technology keeping in view the overall business objectives of a company.

5.3 Aerospace Manufacturer Operations

The aerospace manufacture which collaborated in this research consists of four main customer facing business units namely:

- Civil Aerospace
- Defence Aerospace
- Marine
- Energy

The operational business units consisted of:

- Compression
- Combustion
- Turbine
- Component
- Control

The reason behind organising the operational business unit in the shape as shown in figure 5.1 is the standard operation of a gas turbine which is the heart and soul of an aero engine. A gas turbine shown in figure 5.2 has the compression system consisting of a fan at the front of the engine and a compressor that sits behind the engine. The compressor pushes the compressed air through the core of the engine into the combustion chamber where the air fuel mixture is ignited to produce a rapidly expanding gas stream that drives the turbine which sits in between the combustor and the exhaust and utilises the gas flow to drive the compressor and the fan. The component operations business unit support the customer facing business units in the aftermarket services across a wide range of low volume products or with the products that are manufactured using mature technologies.

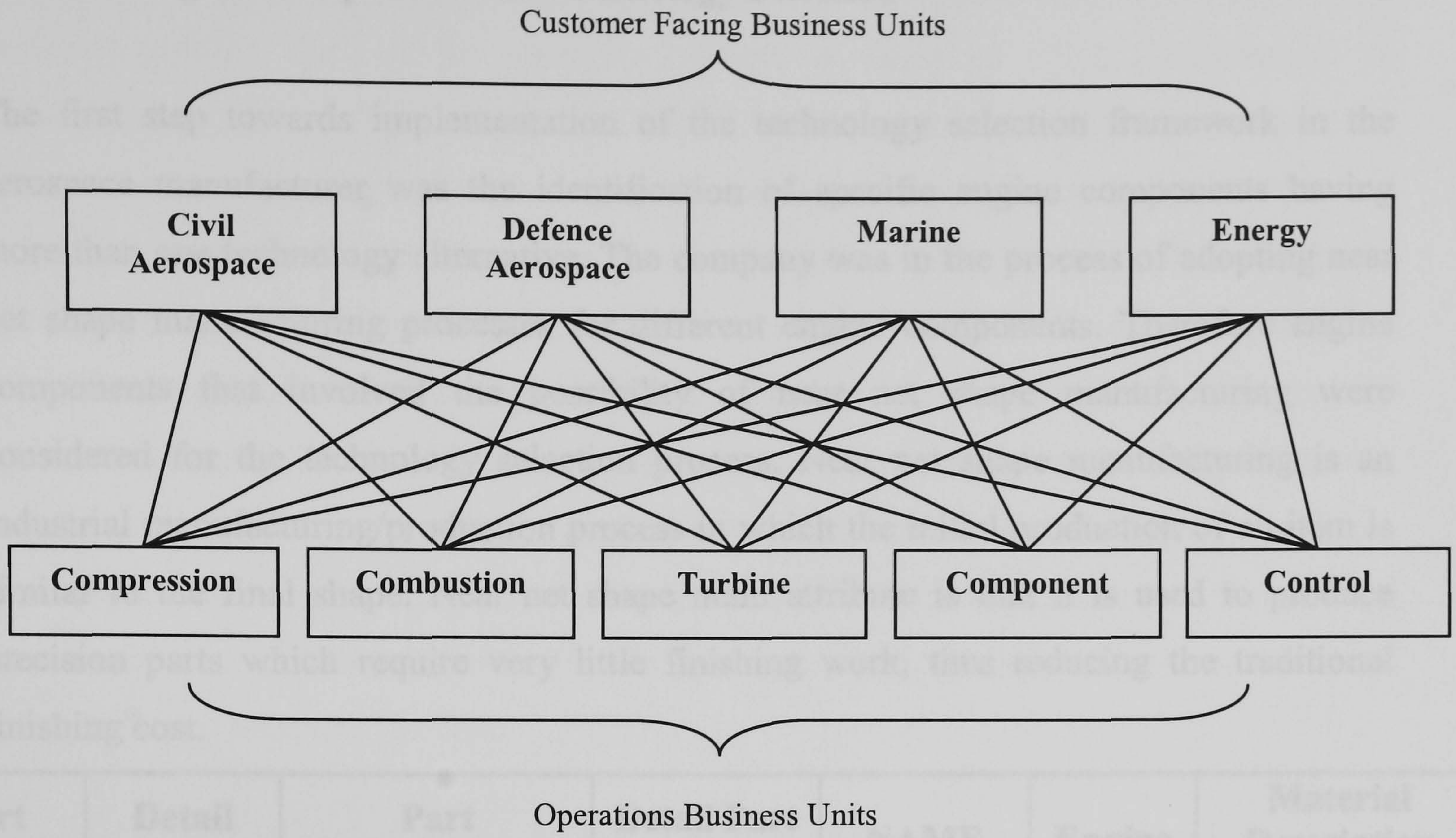

Figure 5.1: Aerospace Manufacturer Operations

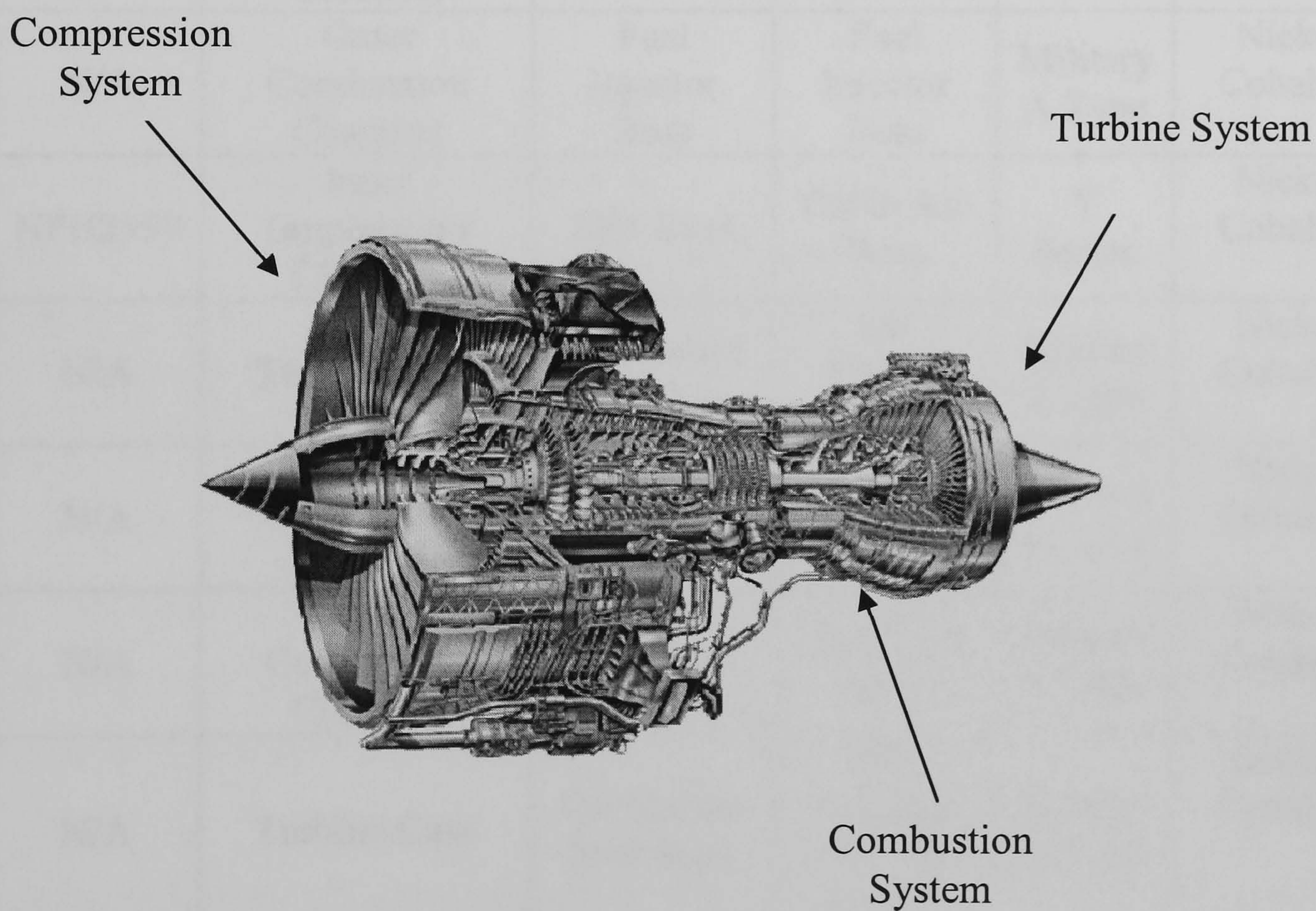

Figure 5.2: A Typical Gas Turbine

5.4 Aero Engine Components for Technology Selection

The first step towards implementation of the technology selection framework in the aerospace manufacturer was the identification of specific engine components having more than one technology alternative. The company was in the process of adopting near net shape manufacturing processes for different engine components. Therefore engine components that involved the possibility of near net shape manufacturing were considered for the technology selection process. Near net shape manufacturing is an industrial manufacturing/production process in which the initial production of an item is similar to the final shape. Near net shape main attribute is that it is used to produce precision parts which require very little finishing work, thus reducing the traditional finishing cost.

Part Number	Detail Part	Part Description	Detail Part Description	NAME	Engine	Material Description
FW15760	NPH2756	Inner Combustion Chamber	HP6 Boss	Cabin Air Boss	X Series	Nickel and Cobalt Alloy
AX70384	N/A	Outer Combustion Chamber	Fuel Injector Boss	Fuel Injector Boss	Military A Type	Nickel and Cobalt Alloy
FW16801	NPH2959	Inner Combustion Chamber	HP6 Boss	Cabin Air Boss	Y Series	Nickel and Cobalt Alloy
NN16492	N/A	Turbine Case	Oil System Inlet Boss	Oil System Inlet Boss	Military E Type	Nickel and Cobalt Alloy
AX70384	N/A	Outer Combustion Chamber	Fuel Injector Boss	Igniter Boss	Military A Type	Nickel and Cobalt Alloy
AX70384	N/A	Outer Combustion Chamber	Fuel Injector Boss	Cabin Air Boss	Military A Type	Nickel and Cobalt Alloy
NN16492	N/A	Turbine Case	Oil System Inlet Boss	HP3 Cooling Air / Oil System	Military E Type	Nickel and Cobalt Alloy

Table 5.1: Engine Components for Technology Selection

Seven different engine components listed in table 5.1, were identified for the technology selection process. Each of the seven components belonged to either a commercial or military aero engine. By looking at table 5.1 it is evident that all the components considered for technology selection were sub parts of either turbine casing or combustion chamber (inner or outer). Each component constituted nickel and cobalt alloy which was necessary to identify as different materials behaved differently for the available manufacturing technologies. Similarly it was necessary to identify each component by part number and part detail as technology managers expected different manufacturing requirements for the parts belonging to different sections of an aero engine. It can be summarised that it was important to identify the actual location of the engine component, its material type and the engine to which it belonged for the successful implementation of the technology selection process.

5.5 Application of the Technology Selection Framework

The application of the technology selection framework involved two phases. The first phase included an evaluation of the current supply chain, critical supply chain factors for competition and the determination of time horizons. The second phase included the identification of manufacturing technologies, a detailed assessment of alternative manufacturing technologies and a risk assessment of identified manufacturing technologies.

5.6 Phase 1

Phase 1 required supply chain managers to provide input regarding the state of their current supply chain, competitive factors for their supply chain and their time period to compete on the identified competitive factors.

The engine components that were selected for the technology selection process were sub parts of either turbine casing or combustion chamber. Therefore supply chain managers from the two operations business unit's turbine and combustion chamber were engaged for evaluation of their supply chains. The managers were required to assess their supply chain according to the questionnaire provided in Appendix C. In the first instance four different managers were separately given the questionnaire for the assessment purpose. Finally a group session was organised to fill in the questionnaire and to agree on the importance and performance of different supply chain performance measures. Next the managers were asked about the time duration they think the product is going to compete on their identified and assessed performance measures. The results showed that turbine and combustion systems have more or less the same importance and performance of different supply chain performance measures. The company was planning to compete on these performance measures for the coming 3-5 years time period at least.

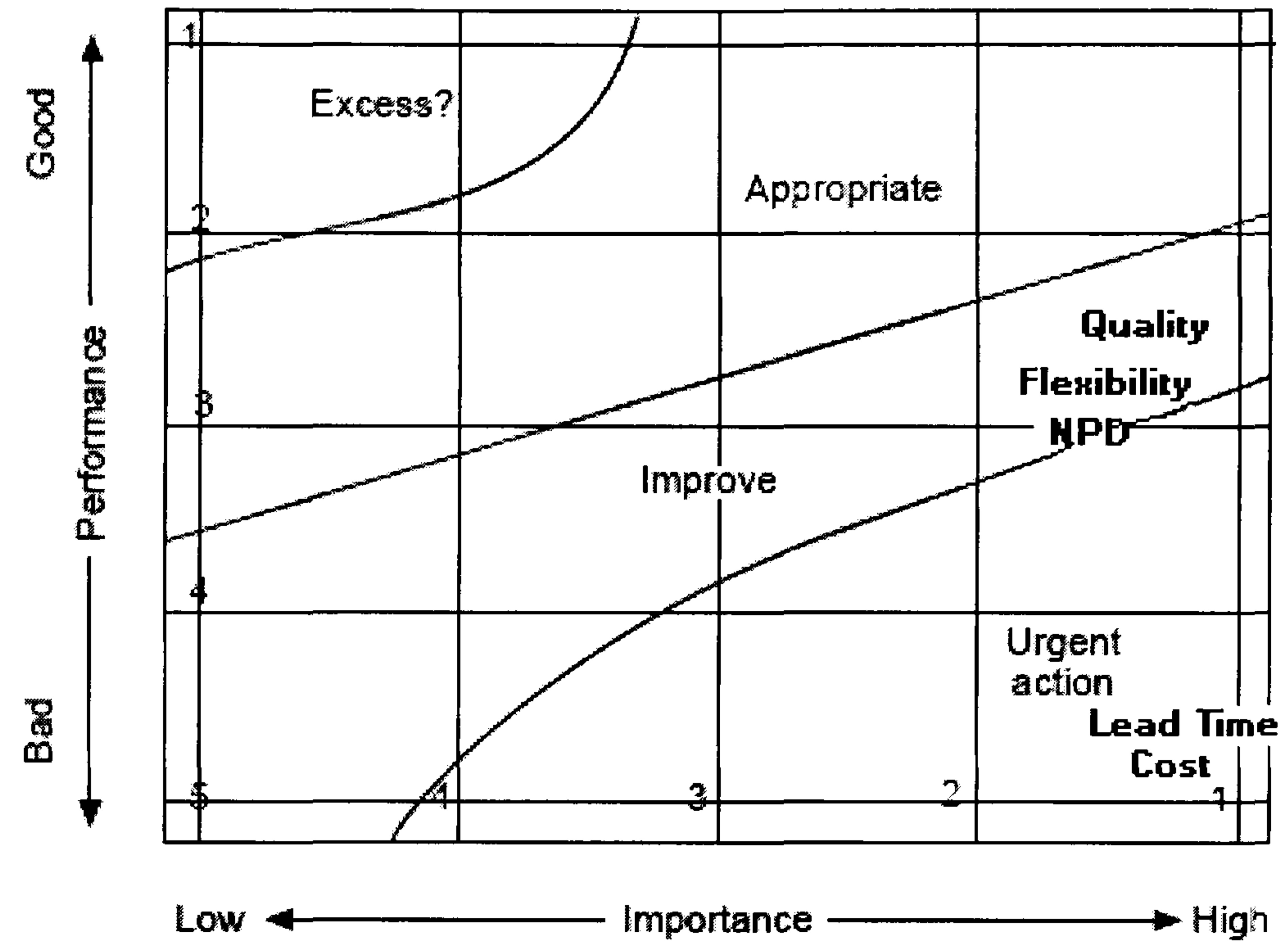

Figure 5.3: Supply Chain Evaluation for Turbine & Combustion Units

From figure 5.3 it is clear that cost and lead time were deemed to be highly important for turbine and combustion unit supply chains. The performance of supply chain in achieving these objectives was unsatisfactory. This resulted in the placement of cost and lead time in the urgent action zone on the importance performance diagram. It showed that the supply chain has to urgently improve in order to achieve a desirable position on the importance performance scale. Whereas in the case of quality, flexibility and new product development (NPD) the performance of the supply chain was just good enough to place them above the urgent action zone on the figure 5.3. They have to improve consistently to remain above the urgent action zone and be in the appropriate section on the importance performance diagram.

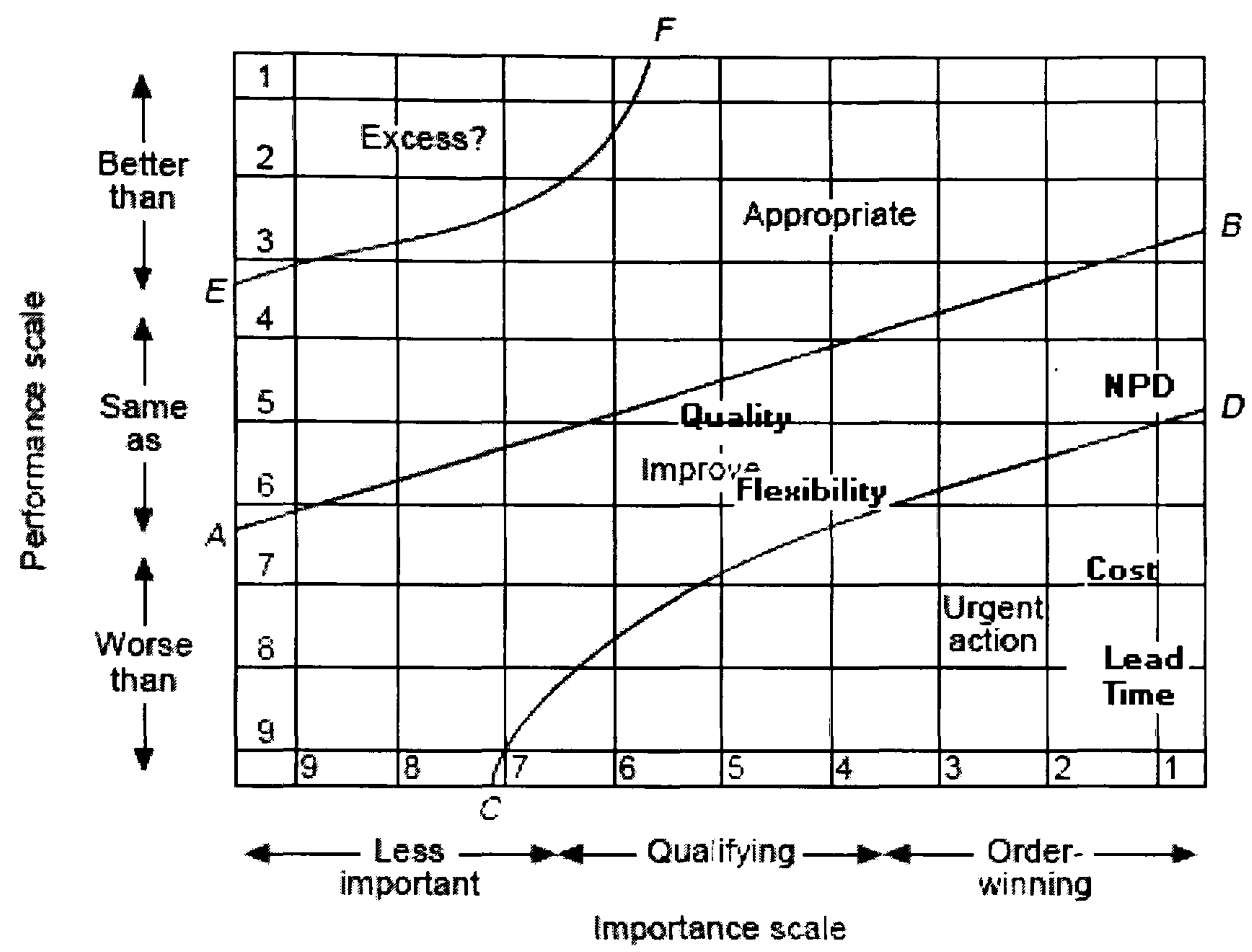

Figure 5.4: Market Evaluation for Turbine & Combustion Units

Market evaluation for turbine and combustion unit is shown in figure 5.4. Similar to the supply chain evaluation case, lead time and cost were the factors that required urgent action, meaning the performance of the aero company with its competitors in achieving cost and lead time was below the industry competitive standards. The company needs to address cost and lead time issues in order to compete in the market and needs to direct it resources to improve these performance measures. Quality, flexibility and new product development (NPD) came in the improvement zone on the importance performance diagram. They needed to be improved consistently to remain competitive.

From both the diagrams 5.3 and 5.4 it is evident that cost and lead time were the factors that caused concern in supply chain as well as the market performance of the company. This shows a relationship between the failure of the supply chain in achieving an appropriate level of performance in cost and lead time resulting in poor performance of the company in the market on the basis of cost and lead time. The main purpose of this evaluation was to have a clear picture of the supply chain and market performance of a particular product of the company. The results were discussed with the technology managers while identifying and selecting the technologies so that they should be aware of the supply chain (business) expectations of their selected manufacturing technologies. According to the above analysis technologies supporting lower costs and shorter lead times were the need of the particular supply chains. So the technology managers were advised to keep these factors with their manufacturing requirements in mind while selecting the technology.

5.7 Phase 2

The second phase of the technology selection process started with the identification of suitable technology alternatives that were capable of manufacturing the selected engine components for the technology selection process. The technology managers involved in the process identified nine different technologies that were evaluated for the technology selection process. Each technology was evaluated by asking questions to the relevant technology manager as every technology was operated by a separate technology manager. The detailed assessment of the technologies using analytical hierarchy process (AHP) was carried out using the Expert Choice Decision Making Software with the managers. The managers were engaged to categorise the opportunities and threats associated with each technology alternative. Finally the risk associated with each technology alternative in terms of opportunities and threats was determined.

5.7.1 Identification of Manufacturing Technologies

Three sets of different manufacturing processes were identified:

- Joining Process
- Solid Process
- Near Net Shape Process

The technologies were classified under the three set of processes as shown in figure 5.5.

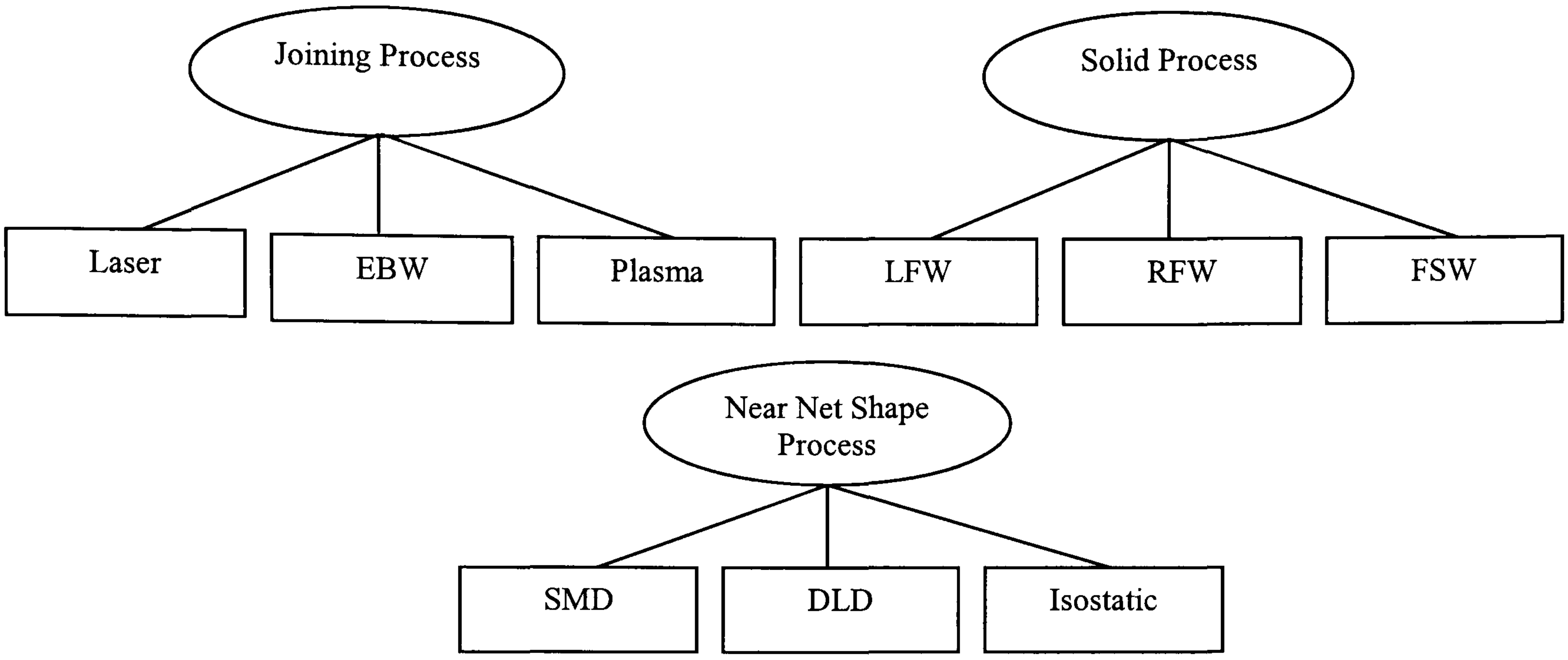

Figure 5.5: Classification of Technologies

5.7.1.1 Laser Welding

Laser welding is a welding technique used to join multiple pieces of metal through the use of a laser. The beam provides a concentrated heat source, allowing for narrow, deep welds and high welding rates. The weld quality is high, similar to that of electron beam welding. The speed of welding is proportional to the amount of power supplied but also depends on the type and thickness of the work pieces. The high power capability of gas lasers make them especially suitable for high volume applications, such as in the automotive industry.

5.7.1.2 Electron beam welding (EBW)

Electron beam welding is a welding process in which a beam of high-velocity electrons is applied to the materials being joined. The work pieces melt as the kinetic energy of the electrons is transformed into heat upon impact, and the filler metal, if used, also melts to form part of the weld. Pressure is not applied, and a shielding gas is not used, though the welding is often done in conditions of a vacuum to prevent dispersion of the electron beam.

5.7.1.3 Plasma Welding

In a plasma welding process, a voltage is applied between an electrode and an object to be welded so as to generate a plasma arc with a plasma gas directed through a torch to surround the electrode, and welding is performed using the plasma arc as a heat source. The process cyclically varies energy contained in the plasma arc by cyclically varying a plasma gas flow rate.

5.7.1.4 Linear Friction Welding

Friction welding is a kind of solid-state welding processes that generates heat through mechanical friction between a moving work piece and a stationary component, with the addition of a lateral force called 'upset' to plastically displace and fuse the materials. Friction welding is used with metals and in a wide variety of aviation and automotive applications. Linear friction welding consists of two chucks for holding the material to be welded. One of the chucks is fixed while the other moves laterally. Linear friction requires more complex machinery than rotary friction welding but it can be used to join parts of different shapes as opposed to rotary friction welding where parts with circular meeting points are entertained.

5.7.1.5 Rotary Friction Welding

Unlike linear friction welding in rotary friction welding one of the chucks holding the material to be welded rotates rather then moving laterally. Before welding one of the work pieces is attached to the rotating chuck along with a flywheel of a given weight. The piece is then spun up to a high rate of rotation to store the required energy in the flywheel. Once spinning at the proper speed, the motor is removed and the pieces forced together under pressure. The force is kept on the pieces after the spinning stops to allow the weld to 'set'.

5.7.1.6 Friction Stir Welding

Friction stir welding is a solid state joining process and is employed to preserve the original characteristics of the metal as long as possible. This process is largely used on large pieces which cannot be easily heat treated after the welding process to regain the lost original characteristics of the metal.

5.7.1.7 Shaped Metal Deposition (SMD)

Shape Metal Deposition (SMD) is a rapid, near net-shaped manufacturing process. It is based on the direct deposition of metal alloys. It offers an accessible, potentially more economical and time-saving alternative compared to many conventional fabrication processes for complex parts. Its major application can be found in aerospace, petrochemical, motor-sport and power generation. Some of its chief advantages can be listed as:

- Rapid Prototyping or Replication
- Low Cost Production
- Low Capital Investment Costs
- Reduced Lead Times
- Reduced Raw Material Costs
- Reliable
- Quality Assured
- Zero Tooling Costs
- Ability to Accommodate Last Minute Design Changes

5.7.1.8 Direct Laser Deposition (DLD)

Direct Laser Deposition (DLD) is a laser deposition process which can be used to quickly produce fully-dense metallic prototypes by a layered manufacturing method. DLD can also be used to repair or modify high-value components. The system includes a laser source configured to emit a laser beam, a target material positioned in front of the laser source to be struck by the laser beam, and a substrate positioned behind the target material in relation to the laser beam. The laser beam strikes the target material causing a portion thereof to melt. The melting zone propagates through the target material until is reaches the opposing surface, and a vaporised portion of the target material is ejected onto the substrate. The target material can be deposited onto the substrate in a pre-determined pattern with a pre-determined thickness.

5.7.1.9 Isostatic

Isostatic process involves joining together component parts of a solid, preferably metallic, material into a composite element by hot isostatic pressing forming the parts so that good contact is obtained between surfaces at a joint where the surfaces are to be joined together. The joint is covered by a layer of a powder or a mixture of powder with substantially the same composition as the material in the different component parts. This powder layer is covered by one or more layers of glass powder. The assembly of parts and layers is pressed isostatically in a known manner at such a temperature that diffusion bonding is achieved at the contact surfaces.

5.7.2 Detailed Assessment of Identified Technologies Using AHP

The AHP decision making environment was divided into three, namely manufacturing, supply chain and general environment, according to the step 5 of the technology selection framework as described in detail in Chapter 4. There were two sets of hierarchies one for the opportunities associated with the technology alternatives and the other one for the threats associated with the technology alternatives. These hierarchies are shown in figure 5.6 and figure 5.7 respectively. The opportunities and threats associated with the technologies were brainstormed in organised sessions with all the nine technology managers involved ensuring that everyone agrees with the identified opportunities and threats. The AHP ranking was carried out by the consensus decision making process of the managers. In order for the managers to be familiarised with the AHP before group decision making process each technology manager was provided a separate questionnaire to compare his technology with a similar kind of technology. An example of such questionnaire is provided in Appendix F. It helped the managers to understand the AHP ranking process and they were able to contribute positively in the collective exercise.

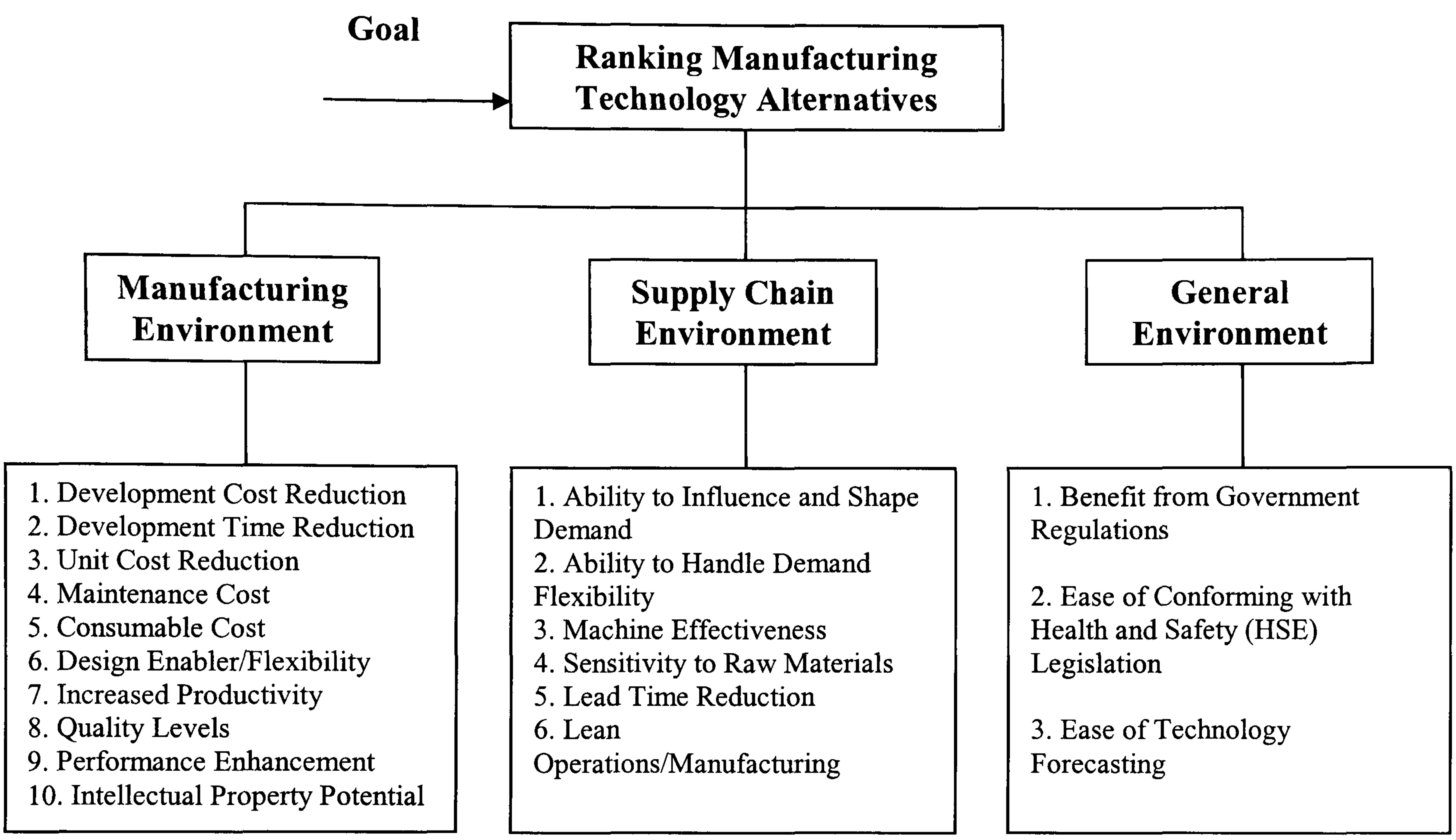

Figure 5.6: AHP Decision Making Hierarchy (Opportunities)

5.7.2.1 Manufacturing Environment Opportunities and Threats

The managers were engaged to brainstorm the opportunities associated with the technologies identified in the manufacturing environment as shown in figure 5.6. This required the managers to list down the opportunities they deemed possible to achieve with the identified set of the manufacturing technologies. These opportunities were considered only on the basis of their usefulness in the manufacturing context. These opportunities were considered from the intra-organisational perspective as they supported the manufacturing functions of the manufacturer. The introduction of development cost reduction as an opportunity was because it deals with the development of welding material that is less liable then conventional materials to distort and the development of new welding methods in conjunction with new materials to make process more precise and reduce energy consumption that would make it possible to eliminate the need for correction by heat treatment. The time employed for the development of such method was categorised as development time as shown in figure 5.6. Costs are more meaningful when they are expressed on a per unit basis, as averages per unit of output. This concept is represented by unit cost in the figure 5.6. The maintenance and consumable costs attached with the welding processes were also listed as manufacturing environment opportunities. The design flexibility, increased productivity and improved quality levels were highlighted as desirable opportunities presented by a technology alternative as shown in figure 5.6. The intellectual property potential and performance enhancement demonstrated by a technology alternative were considered as important opportunities by the managers in the technology evaluation and technology selection process.

Similarly, the threats associated with the technologies in the manufacturing environment were considered as described in figure 5.7. These threats were critical in the view of the managers for their manufacturing operations. The threats in the manufacturing environment were also from the intra-organisational perspective as they were identified by keeping in mind the manufacturing objectives of the aero manufacturer. The capital cost of the technology alternative and the resistance of staff in adopting the new technology were mentioned as the foremost threats in the manufacturing environment. In the same fashion the training expenses for staff and the system integration of the selected technology alternative were considered as major concerns. The maturity of the advanced and recently developed technology alternatives was highlighted as a noticeable threat as shown in figure 5.7. The installation of new equipment to support a selected technology alternative and the incapability of the technology to respond instantly to a manufacturing change request were documented as threats in the manufacturing environment.

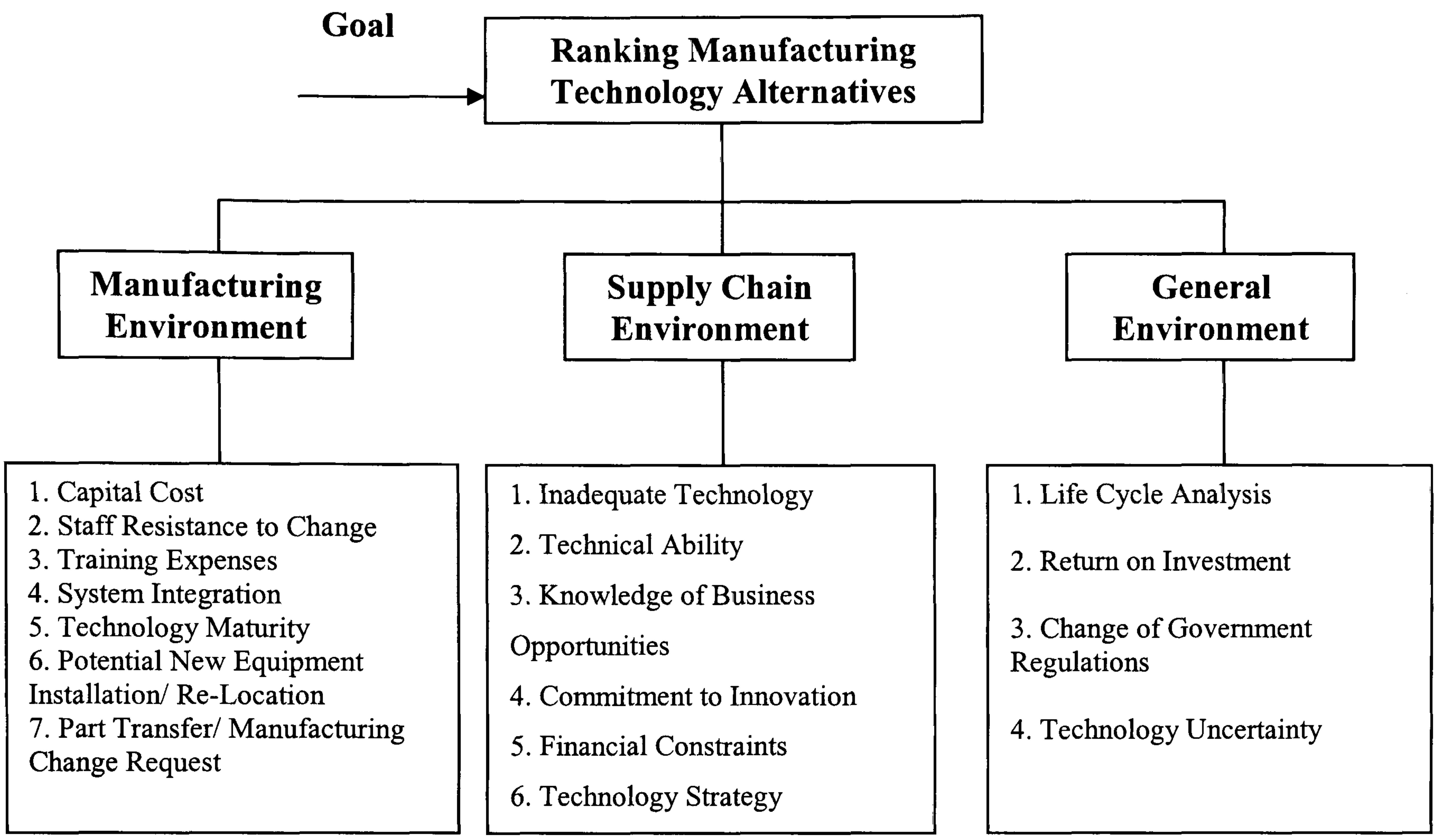

Figure 5.7: AHP Decision Making Hierarchy (Threats)

5.7.2.2 Supply Chain Environment Opportunities and Threats

In this case the opportunities associated with the technologies were considered by the managers from a supply chain perspective as given in figure 5.6. They were guided to brainstorm the factors that could be beneficial to their supply chain as a consequence of their technology selection. The main aim of this process was to encourage the technology mangers to consider how there could be benefit to their supply chain if they consider their supply chain characteristics when making key strategic decisions. The process for identification of the opportunities from considering the supply chain view needed some more explanation to the mangers as they were not familiar with selecting a technology by considering their supply chain. The managers had some hesitation at the start in ranking the technologies according to the opportunities identified considering the supply chain but after understanding the logic of the process they contributed positively towards the evaluation process. This introduced a new approach to the company in selecting manufacturing technology and provided them with another angle from which to look at the technology selection process. The selection of a technology alternative that facilitates the ability to influence demand and provides flexibility to handle the influenced demand at intra as well as inter-organisational level was considered as an opportunity that could help to integrate a supply chain. The selection of a technology alternative by an organisation by considering the machine effectiveness, sensitivity to raw materials and lean operations of the technology and the effect of these technology capabilities on the supply chain operations could provide an opportunity to bring supply chain considerations into an organisation's technology selection decision making process.

The threats associated with the technologies were also defined from inter -organisational concerns as shown in figure 5.7. The supply chain was considered while listing down the threats. How the selection of a particular technology could be unbeneficial for the supply chain was visualised. The selection of technology based on supply chain threats provided a step towards the integration of the supply chain by considering the needs of the supply chain in the strategic technology selection decision making process. The lack of technical ability and inadequate technology available with the supply chain to support the technology alternative selected by an organisation could be detrimental to achieving the goal of an organisation and eventually the goals of an entire supply chain. Similarly, lack of business opportunity knowledge, low commitment to innovation and financially constrained technology strategy of the supply chain could play a decisive role in the success or failure of a selected technology alternative in achieving its intra as well as inter-organisational objectives.

5.7.2.3 General Environment Opportunities and Threats

There were a set of factors that were classified under the general environment which contributed towards the technology evaluation. These factors were brainstormed by the managers by considering the impact of these factors on the technology selection process. The opportunities in the general environment are shown in figure 5.6. The ability of a technology alternative to benefit from the government regulations on industrial and environmental pollution and the conformance of the technology alternative to health and safety regulations was considered as an opportunity by the managers. The ease with which the future of a technology alternative could be forecasted was also mentioned as an opportunity as it helped in making the subsequent organisational decisions that are based on the technology forecasting and technology selection process.

In the general environment some threats were also identified that played a role in the technology selection process as shown in figure 5.7. The life cycle assessment also known as 'cradle to grave analysis' was recognised as an important concern as stringent global and regional environmental legislations are making it difficult to select a technology alternative that satisfies these legislations and also fulfils the technical and commercial objectives of an organisation. The managers also considered low returns on investment with technology uncertainty as major concerns in the technology evaluation process.

5.7.3 Risk Assessment of the Technology Alternatives

The next step after the classification of opportunities and threats associated with the technology alternatives and the detailed assessment of the technologies using the AHP methodology was the calculation of the risk associated with the identified opportunities and threats. The basic aim of the risk determination was to identify the opportunities and threats towards which the technology managers were more risk averse compared to the other opportunities and threats towards which they were risk neutral. The determination of a risk aversion factor for each opportunity and threat helped in the final evaluation of the technology alternative as it provided the technology selection process with a sense of comprehensiveness by including the role of risk determination associated with technology alternatives in the technology selection process.

The managers were instructed to identify the probability of occurrence of an opportunity and threat considering every identified technology alternative and each identified engine component in table 5.1 as shown in Appendix D. For example, table 5.2, 5.3 and 5.4

shows the probability of occurrence of each opportunity in the manufacturing, supply chain and general environments identified in figure 5.6 with respect to electron beam welding technology considering the first engine component identified in table 5.1.

Opportunities	Probability of Occurrence
Development Cost Reduction	0.9
Development Time Reduction	0.5
Unit Cost Reduction	0.9
Maintenance Cost	0.8
Consumable Cost	0.5
Design Enabler/Flexibility	0.6
Increased Productivity	0.6
Quality Levels	0.7
Performance Enhancement	0.6
Intellectual Property Potential	0.5

Table 5.2: Probability of Occurrence of Opportunities in the Manufacturing Environment

Opportunities	Probability of Occurrence
Ability to Influence Shape and Demand	0.5
Ability to Handle Demand Flexibility	0.6
Machine Effectiveness	0.5
Sensitivity to Raw Materials	0.6
Lead Time Reduction	0.6
Lean Operations/Manufacturing	0.6

Table 5.3: Probability of Occurrence of Opportunities in the Supply Chain Environment

Opportunities	Probability of Occurrence
Benefits from Government Regulations	0.7
Ease of Conforming with HSE Legislation	0.7
Ease of Technology Forecasting	0.8

Table 5.4: Probability of Occurrence of Opportunities in the General Environment

Similarly the probability of occurrence of threats identified in figure 5.7 considering manufacturing, supply chain and general environment are presented in table 5.5, 5.6 and 5.7 for the electron beam welding technology for the first engine component.

Threats	Probability of Occurrence
Capital Cost	0.1
Staff Resistance to Change	0.2
Training Expenses	0.3
System Integration	0.2
Technology Maturity	0.4
Potential New Equipment Installation/ Re-Location	0.1
Part Transfer/ Manufacturing Change Request	0.3

Table 5.5: Probability of Occurrence of Threats in the Manufacturing Environment

Threats	Probability of Occurrence
Inadequate Technology	0.1
Technical Ability	0.2
Knowledge of Business Opportunities	0.3
Commitment to Innovation	0.1
Financial Constraints	0.4
Technology Strategy	0.2

Table 5.6: Probability of Occurrence of Threats in the Supply Chain Environment

Threats	Probability of Occurrence
Life Cycle Analysis	0.3
Return on Investment	0.2
Change of Government Regulations	0.2
Technology Uncertainty	0.1

Table 5.7: Probability of Occurrence of Threats in the General Environment

From table 5.2 it is clear that the probability of achieving a development cost reduction (0.9) with electron beam welding when considering the first engine component is very high. In the supply chain environment the probability of achieving a lead time reduction was 60% (0.6) given in table 5.3 when considering the electron beam welding as the manufacturing technology. The process of technology forecasting was supposed to be easy with electron beam welding as it provided a higher probability of occurrence value (0.8) as shown in table 5.4. The probability of the highest threat occurring in the manufacturing environment was about the technology maturity (0.4) as shown in table 5.5. The highest threats occurring in the supply chain and general environment according to table 5.6 and table 5.7 were financial constraints (0.4) and technology life cycle analysis (0.3). The probability of occurrence of opportunities and threats in the manufacturing, supply chain and general environment were determined for each technology alternative and each engine component identified in table 5.1. The probability of occurrence of threats associated with technology alternatives for different engine components remained the same. The reasons for the similarities are given in Chapter 7.

The risk aversion factor for each of the identified opportunities and threats was calculated using Appendix I and are described in table 5.8, 5.9, 5.10, 5.11, 5.12 and table 5.13.

Opportunities	Risk Aversion Factor
Development Cost Reduction	0.08
Development Time Reduction	0.08
Unit Cost Reduction	0.8
Maintenance Cost	0.08
Consumable Cost	0.08
Design Enabler/Flexibility	0.2
Increased Productivity	0.8
Quality Levels	0.8
Performance Enhancement	0.4
Intellectual Property Potential	0.2

Table 5.8: Risk Aversion Factor for Opportunities in the Manufacturing Environment

Opportunities	Risk Aversion Factor
Ability to Influence Shape and Demand	0.2
Ability to Handle Demand Flexibility	0.8
Machine Effectiveness	0.8
Sensitivity to Raw Materials	0.08
Lead Time Reduction	0.8
Lean Operations/Manufacturing	0.4

Table 5.9: Risk Aversion Factor for Opportunities in the Supply Chain Environment

Opportunities	Risk Aversion Factor
Benefits from Government Regulations	0.2
Ease of Conforming with HSE Legislation	0.6
Ease of Technology Forecasting	0.8

Table 5.10: Risk Aversion Factor for Opportunities in the General Environment

Threats	Risk Aversion Factor
Capital Cost	0.8
Staff Resistance to Change	0.2
Training Expenses	0.08
System Integration	0.08
Technology Maturity	0.4
Potential New Equipment Installation/ Re-Location	0.4
Part Transfer/ Manufacturing Change Request	0.8

Table 5.11: Risk Aversion Factor for Threats in the Manufacturing Environment

Threats	Risk Aversion Factor
Inadequate Technology	0.08
Technical Ability	0.8
Knowledge of Business Opportunities	0.08
Commitment to Innovation	0.08
Financial Constraints	0.8
Technology Strategy	0.2

Table 5.12: Risk Aversion Factor for Threats in the Supply Chain Environment

Threats	Risk Aversion Factor
Life Cycle Analysis	0.8
Return on Investment	0.8
Change of Government Regulations	0.06
Technology Uncertainty	0.6

Table 5.13: Risk Aversion Factor for Threats in the General Environment

Risk aversion calculations for each opportunity and threat were based on the process detailed in step 6 of the technology selection framework in Chapter 4. From table 5.8 it is evident that the highest risk aversion value (0.8) was attributed to unit cost reduction, quality levels and increased productivity. This means that the managers were more risk averse towards these factors compared to the other opportunities identified. Similarly in the supply chain environment opportunities, machine effectiveness, ability to handle demand flexibility and lead time reduction had the highest risk aversion value (0.8) showing the sensitivity of the managers towards these opportunities when selecting their manufacturing technologies. Ease of technology forecasting in the general environment opportunities also had a high risk aversion value (0.8) as shown in table 5.10. The risk aversion values associated with threats showed that in the manufacturing environment, capital cost and manufacturing change request (0.8) had the highest risk aversion factor. Technical ability and financial constraint (0.8) in the supply chain threats whereas life cycle analysis and return on investment (0.8) in the general environment threats had the highest risk aversion value as shown in table 5.12 and 5.13. Finally using these risk aversion factors the overall risk adjusted technology strategic value was calculated. The results for overall risk adjusted strategic values for each of the identified engine component in table 5.1 are explained in detail in Chapter 6.

5.8 Conclusion

The successful implementation of the technology selection framework in the aerospace manufacturer required co-ordination between the participating managers, and their knowledge of the supply chain and the manufacturing technologies. The supply chain managers who participated in the implementation of the technology selection framework were well versed in identifying the market competition factors for their products. The knowledge of the supply chain managers helped in the market evaluation of the selected products against their major market competitor. The supply chain managers were readily able to identify the weak links in their supply chain and they fully understood the effect of these weaknesses on the market performance of their products. The link between the supply chain performance and the market performance was the key towards identifying the importance of the supply chain in achieving the business objectives. The technology managers were well educated about the latest manufacturing technologies. They quickly identified the manufacturing requirements expected from a manufacturing technology. However at first they struggled to identify the supply chain factors that can affect a choice of manufacturing technology. Brainstorming sessions with the managers helped them to realise the concept of supply chain and they were able to identify the factors that can play a role in technology selection from a supply chain perspective. The introduction of opportunities and threats in the technology selection process was new to the technology managers. They were comfortable with the opportunities identification process but they showed their concerns when threats associated with different manufacturing technology were highlighted. The inclusion of threats associated with technology alternatives provided a new dimension to the technology selection process by comprehensively evaluating all the manufacturing technology alternatives on the basis of opportunity and threat associated with them. The risk aversion calculations in the technology selection framework were useful in visualising the way company managers perceived opportunities and threats associated with different technology alternatives. The risk aversion calculation method required repeated explanation to the managers in the company as the risk calculation method included first calculating certainty equivalence and then the risk aversion factor from the assigned certainty equivalence value.

This chapter has introduced the case study by first describing the background of the aerospace manufacturer where the developed technology selection framework was employed. The chapter explains in detail the process of implementation of the technology selection framework in the aerospace manufacturer. In the next chapter the results of the technology selection process are described in detail for each of the engine components identified in table 5.1 and the functional as well as holistic integration of the technology selection framework in the aerospace manufacturer is explained.

Chapter 6

Case Study Analysis

6.1 Introduction

This chapter describes in detail the assessment of results for technology alternatives for each of the engine components considered in this study. The results have been classified into analytical hierarchy process results (AHP) and strategic assessment model (SAM) results which are the two methods employed in the technology selection framework. The difference between the two evaluation approaches and their results are also discussed. The chapter describes the existing decision making process at the aerospace manufacturer and how the proposed technology selection framework can be integrated with the existing decision making process at the company. Finally the usefulness of the technology selection process for the aerospace manufacturer is documented.

6.2 Component 1 Cabin Air Boss (Engine X Series)

The first component selected for technology evaluation was part of the combustion chamber and belonged to the commercial engine series X. Detailed calculations for the technology selection were carried out using step 5 and step 6 of the technology selection framework described in Chapter 4. In the following section some of the results from AHP and SAM are described and their significance explained.

6.2.1 AHP Results (Opportunities)

By considering figure 6.1 it is obvious that friction stir welding (FSW) was deemed to be the best suitable technology alternative while keeping in view the opportunities associated with each technology alternative. The manufacturing environment (63.4%) contributed the highest towards the decision making process. The supply chain (19.2%)

and general environment (17.4%) were the subsequent contributors in the decision making environment for the technology selection. The results for component 1 are computed in the following table 6.1:

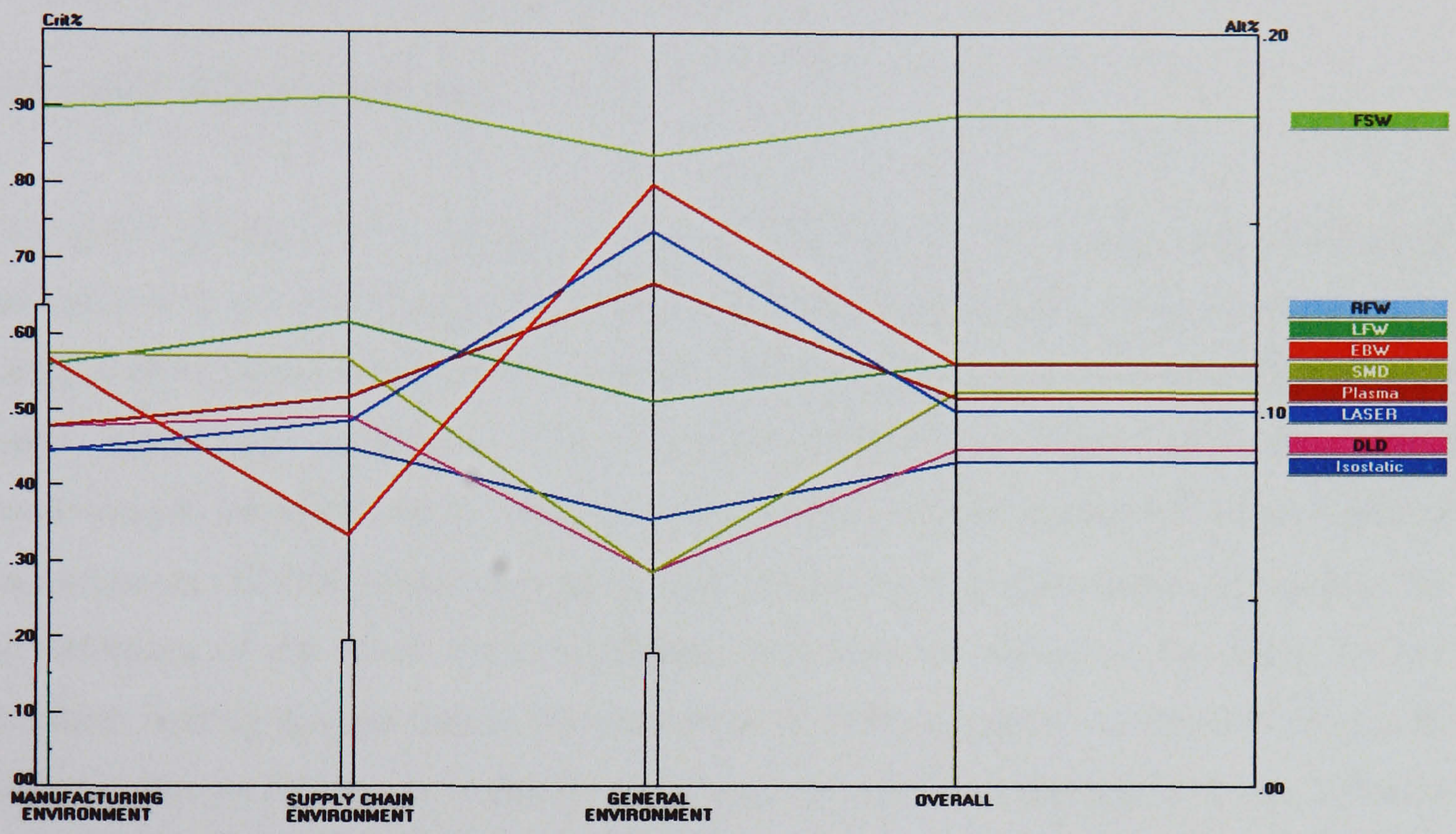

Figure 6.1: AHP Technology Performance Graph for Component 1 (Opportunities)

Name of Technology	**% Contribution Towards Technology Suitability**
Friction Stir Welding (FSW)	17.8 %
Rotary Friction Welding (RFW)	11.3%
Linear Friction Welding (LFW)	11.3%
Electron Beam Welding (EBW)	11.2%
Shape Metal Deposition (SMD)	10.5%
Plasma	10.3%
Laser Welding	10.0%
Direct Laser Deposition (DLD)	9.0%
Isostatic	8.6%

Table 6.1: AHP Technology Ranking Table (Opportunities)

From the above table it is clear that friction stir welding (17.8%) is the most suitable technology alternative while isostatic (8.6%) is the least favourable when the opportunities associated with technology alternatives are included in the decision making process.

6.2.2 AHP Results (Threats)

An AHP hierarchy for threats (shown in Chapter 5) associated with technology alternatives was constructed and evaluated. As shown in the figure 6.2 Plasma technology seemed to be the most favourable candidate while considering the threats associated with each technology alternative. The decision makers gave each decision making environment the same values- manufacturing (63.4%), supply chain (19.2 %) and general environment (17.4%), which they gave while evaluating the opportunities hierarchy. The contribution of the three decision making environments remained the same for the decision making process during the evaluation of different engine components. Similarly the calculations for threats remained unchanged during the evaluation of seven different engine components. The reasons for this are explained in Chapter 7 under the limitations of this research.

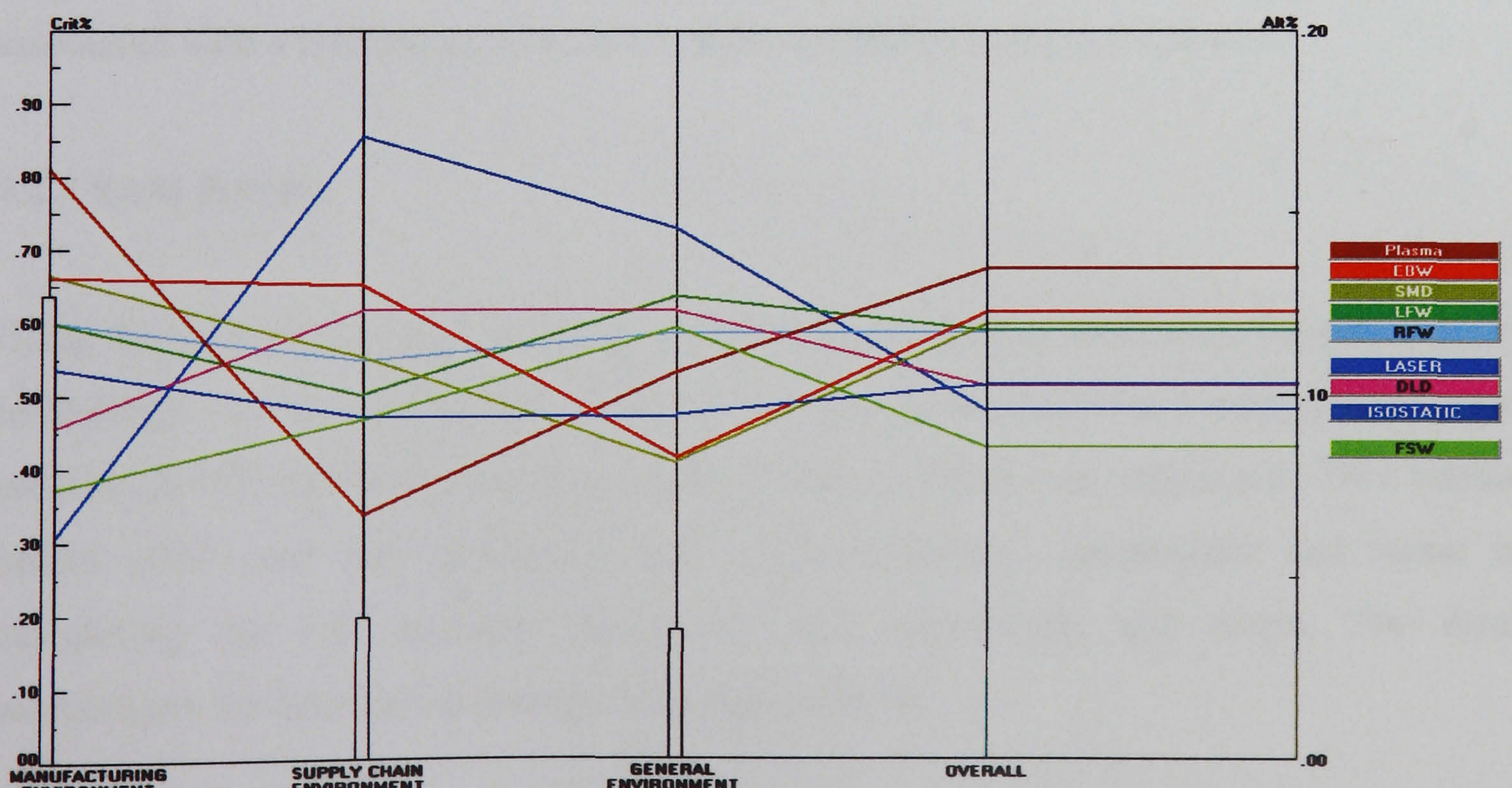

Figure 6.2: AHP Technology Performance Graph for Component 1 (Threats)

Name of Technology	% Contribution Towards Technology Suitability
Plasma	13.5%
Electron Beam Welding (EBW)	12.3%
Shape Metal Deposition (SMD)	12.0%
Linear Friction Welding (LFW)	11.8%
Rotary Friction Welding (RFW)	11.8%
Laser Welding	10.3%
Direct Laser Deposition (DLD)	10.3%
Isostatic	9.6%
Friction Stir Welding (FSW)	8.6%

Table 6.2: AHP Technology Ranking Table (Threats)

Table 6.2 shows that when the threats associated with each technology alternative were considered in the decision making process plasma (13.5%) seemed to be the best technology alternative. An interesting finding was friction stir welding (8.6%) whose suitability was the lowest when considering the threats. It had the highest value for the opportunities as shown in table 6.1. This shows that a technology can provide opportunities and threats at the same time and therefore both opportunities and threats associated with a technology should be evaluated before making a selection.

6.2.3 SAM Results

Using the final step of the technology selection framework to determine the risk adjusted technology strategic value for different technology alternatives, strategic assessment method (SAM) developed by Tavana & Banerjee (1995) was employed. This method unlike AHP uses risk associated with each technology opportunity and threat by calculating the risk aversion factor for each opportunity and threat. The detail calculations for SAM are documented in Appendix H.

The following table 6.3 shows risk adjusted strategic values for opportunities associated with each technology alternative. If only the manufacturing environment opportunities were considered it is apparent from the table that friction stir welding (0.432) is the best suited technology alternative. In the case of supply chain (0.148) as well general environment (0.127) friction stir welding was the most desired technology alternative.

Similarly the risk adjusted strategic values for threats are shown in table 6.4. According to the table the biggest threat in the manufacturing environment (-0.296) and the supply chain environment (-0.069) was associated with isostatic technology. In the general environment threats, friction stir welding (-0.09) was the technology presenting the highest level of threat. The SAM calculations for threats associated with technologies in each case of the seven different engine components remained the same and causes for this uniformity in calculations is described in Chapter 7 under the limitations of this research.

Finally the overall risk adjusted strategic values for the technology alternatives were computed as shown in table 6.5. The overall risk adjusted strategic value is the sum of the risk adjusted opportunity value and the risk adjusted threat value. From table 6.5 it is clear that plasma technology (0.360) had the highest value when considering the risk associated with technology alternatives and calculating the risk aversion factor for each opportunity and threats. It is surprising in the context that plasma technology was not the highest favoured technology alternative in manufacturing environment, supply chain environment and general environment in the cases of opportunities as shown in table 6.3. But it offered a considerably lower level of threat as compared to other favourable technologies, especially friction stir welding, as shown in table 6.4 that contributed towards its successful strategic selection. It is evident from this example that a technology does not only have to present maximum opportunities but also have to reduce the threats associated with it for successful evaluation.

Manufacturing Technology	Manufacturing Environment	Supply Chain Environment	General Environment
Laser Technology	0.325	0.106	0.112
Electron Beam Welding	0.396	0.090	0.120
Plasma Technology	0.318	0.124	0.104
Linear Friction Welding	0.349	0.127	0.098
Rotary Friction Welding	0.349	0.127	0.098
Friction Stir Welding	0.432	0.148	0.127
Shaped Metal Deposition	0.359	0.125	0.073
Direct Laser Deposition	0.307	0.119	0.073
Isostatic Technology	0.305	0.118	0.081

Table 6.3: Risk Adjusted Strategic Value (Opportunities)

Manufacturing Technology	Manufacturing Environment	Supply Chain Environment	General Environment
Laser Technology	-0.211	-0.060	-0.060
Electron Beam Welding	-0.167	-0.067	-0.040
Plasma Technology	-0.113	-0.043	-0.030
Linear Friction Welding	-0.163	-0.060	-0.050
Rotary Friction Welding	-0.163	-0.065	-0.060
Friction Stir Welding	-0.264	-0.044	-0.090
Shaped Metal Deposition	-0.123	-0.043	-0.070
Direct Laser Deposition	-0.197	-0.054	-0.070
Isostatic Technology	-0.296	-0.069	-0.040

Table 6.4: Risk Adjusted Strategic Value (Threats)

Manufacturing Technology	Overall Risk Adjusted Opportunity Value	Overall Risk Adjusted Threat Value	Overall Risk Adjusted Strategic Value
Laser Technology	0.542	-0.331	0.211
Electron Beam Welding	0.606	-0.274	0.332
Plasma Technology	0.546	-0.186	0.360
Linear Friction Welding	0.574	-0.273	0.301
Rotary Friction Welding	0.574	-0.288	0.286
Friction Stir Welding	0.707	-0.398	0.309
Shaped Metal Deposition	0.557	-0.236	0.321
Direct Laser Deposition	0.499	-0.321	0.178
Isostatic Technology	0.504	-0.405	0.099

Table 6.5: Overall Risk Adjusted Strategic Value

6.3 Component 2 Fuel Injector Boss (Military Engine A Type)

The second component used for the technology selection process was also part of the combustion chamber and belonged to a military jet engine. Detailed calculations were carried out as in the case of first component and the significant results from the AHP analysis and SAM calculations are described below.

6.3.1 AHP Results (Opportunities)

Electron beam welding was the most suitable technology considering the AHP opportunities hierarchy as shown in figure 6.3. There was a strong competition between electron beam welding (13.2%) and friction stir welding (13.1%). Plasma technology (9.2%) deemed to be the most unsuitable technology alternative.

As mentioned earlier the AHP results for threats for all the seven components are similar in each case so therefore they are not discussed separately for every component.

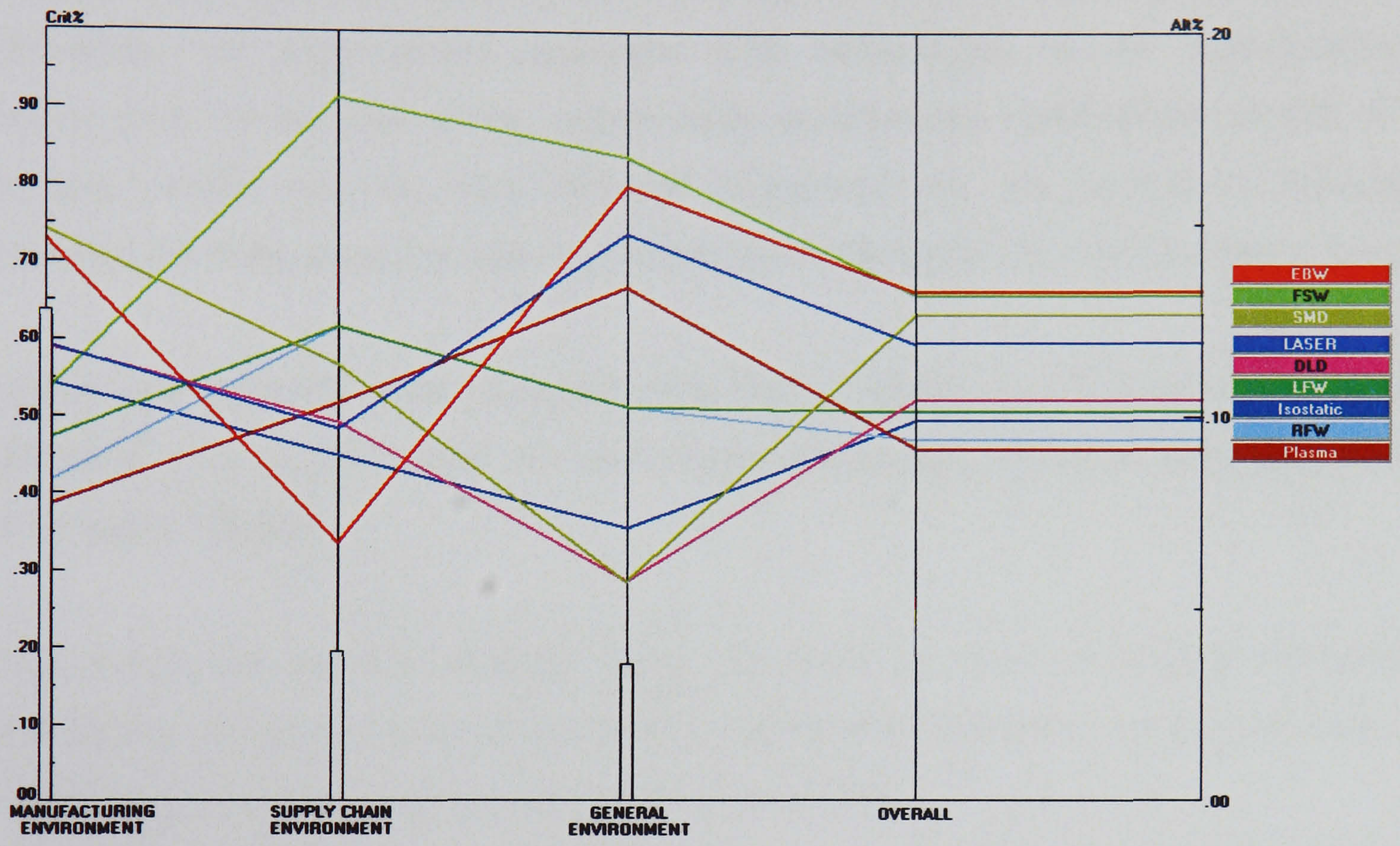

Figure 6.3: AHP Technology Performance Graph for Component 2 (Opportunities)

Name of Technology	% Contribution Towards Technology Suitability
Electron Beam Welding (EBW)	13.2 %
Friction Stir Welding (FSW)	13.1%
Shape Metal Deposition (SMD)	12.7%
Laser Welding	11.9%
Direct Laser Deposition (DLD)	10.4%
Linear Friction Welding (LFW)	10.1%
Isostatic	9.9%
Rotary Friction Welding (RFW)	9.4%
Plasma	9.2%

Table 6.6: AHP Technology Ranking Table (Opportunities)

6.3.2 SAM Results

As with the first component, SAM calculations were carried out and are provided in the Appendix H. The following table 6.7 shows the risk adjusted opportunity values and indicates that shaped metal deposition (0.505) was the most favoured technology when considering the opportunities associated with technologies in the manufacturing environment. In the case of the supply chain environment opportunities friction stir welding (0.148) was the most favoured technology and the general environment opportunities were supported again by friction stir welding (0.127) with the highest value.

In this case the SAM value associated with threats offered by the technologies is not discussed here as the values for each seven components remained same and it is discussed in Chapter 7.

The overall risk adjusted strategic value computed for each technology alternative showed that shaped metal deposition (0.467) was the most suitable technology alternative considering the decision makers risks aversion priorities.

Manufacturing Technology	Manufacturing Environment	Supply Chain Environment	General Environment
Laser Technology	0.400	0.106	0.112
Electron Beam Welding	0.498	0.090	0.120
Plasma Technology	0.333	0.124	0.104
Linear Friction Welding	0.363	0.127	0.098
Rotary Friction Welding	0.292	0.127	0.098
Friction Stir Welding	0.292	0.148	0.127
Shaped Metal Deposition	0.505	0.125	0.073
Direct Laser Deposition	0.465	0.119	0.073
Isostatic Technology	0.469	0.118	0.081

Table 6.7: Risk Adjusted Strategic Value (Opportunities)

Manufacturing Technology	Overall Risk Adjusted Opportunity Value	Overall Risk Adjusted Threat Value	Overall Risk Adjusted Strategic Value
Laser Technology	0.618	-0.331	0.287
Electron Beam Welding	0.708	-0.274	0.434
Plasma Technology	0.561	-0.186	0.375
Linear Friction Welding	0.588	-0.273	0.315
Rotary Friction Welding	0.517	-0.288	0.229
Friction Stir Welding	0.567	-0.398	0.169
Shaped Metal Deposition	0.703	-0.236	0.467
Direct Laser Deposition	0.657	-0.321	0.336
Isostatic Technology	0.668	-0.405	0.263

Table 6.8: Overall Risk Adjusted Strategic Value

6.4 Component 3 Cabin Air Boss (Engine Y Series)

The third component used in this technology selection evaluation process was another cabin air boss of commercial engine series Y. Important highlights of the AHP and SAM are explained in this section.

6.4.1 AHP Results (Opportunities)

In this case friction stir welding (17.4%) was the most suitable technology alternative and Isostatic (9.2%) was deemed to be the least suitable technology alternative using the AHP methodology while considering opportunities associated with each technology alternative.

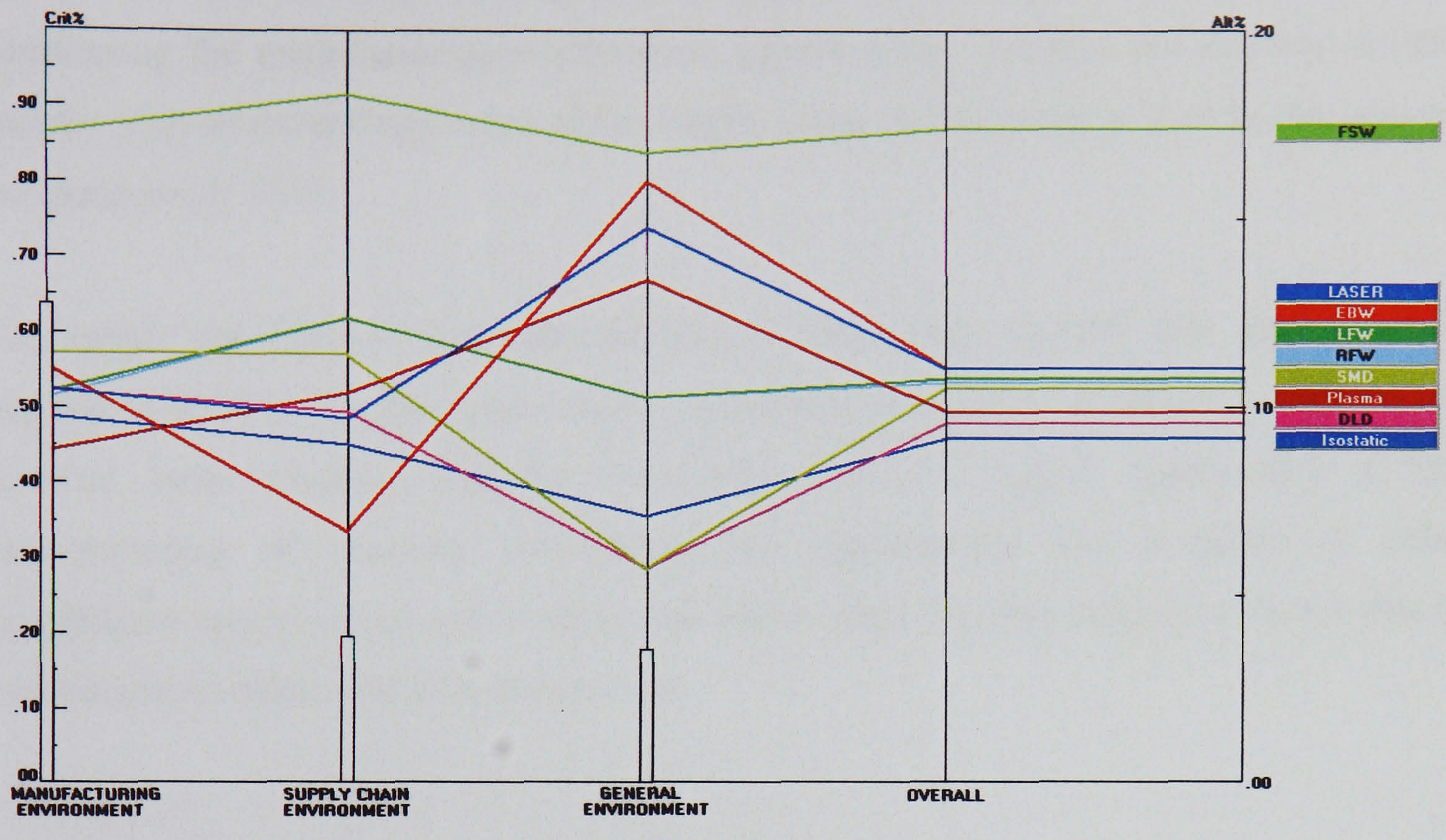

Figure 6.4: AHP Technology Performance Graph for Component 3 (Opportunities)

Name of Technology	**% Contribution Towards Technology Suitability**
Friction Stir Welding (FSW)	17.4 %
Laser Welding	11.0%
Electron Beam Welding (EBW)	11.0%
Linear Friction Welding (LFW)	10.8%
Rotary Friction Welding (RFW)	10.7%
Shape Metal Deposition (SMD)	10.5%
Plasma	9.9%
Direct Laser Deposition (DLD)	9.6%
Isostatic	9.2%

Table 6.9: AHP Technology Ranking Table (Opportunities)

6.4.2 SAM Results

In this case electron beam welding (0.403) was the most suitable technology alternative considering the manufacturing environment opportunities. Friction stir welding (0.148) had the highest technology value in the supply chain environment as well as the general environment (0.127).

The major competition was between plasma technology (0.359) and shaped metal deposition (0.351) for the most suitable technology alternative as shown in table 6.11. Electron beam welding was the technology with the highest appreciation in the manufacturing environment considering the opportunities but it failed to offer competitive opportunities and to reduce threats in other decision making environments in comparison to other available technologies.

Manufacturing Technology	Manufacturing Environment	Supply Chain Environment	General Environment
Laser Technology	0.358	0.106	0.112
Electron Beam Welding	0.403	0.090	0.120
Plasma Technology	0.317	0.124	0.104
Linear Friction Welding	0.356	0.127	0.098
Rotary Friction Welding	0.353	0.127	0.098
Friction Stir Welding	0.376	0.148	0.127
Shaped Metal Deposition	0.389	0.125	0.073
Direct Laser Deposition	0.353	0.119	0.073
Isostatic Technology	0.346	0.118	0.081

Table 6.10: Risk Adjusted Strategic Value (Opportunities)

Manufacturing Technology	Overall Risk Adjusted Opportunity Value	Overall Risk Adjusted Threat Value	Overall Risk Adjusted Strategic Value
Laser Technology	0.576	-0.331	0.245
Electron Beam Welding	0.613	-0.274	0.339
Plasma Technology	0.545	-0.186	0.359
Linear Friction Welding	0.581	-0.273	0.308
Rotary Friction Welding	0.578	-0.288	0.290
Friction Stir Welding	0.652	-0.398	0.254
Shaped Metal Deposition	0.587	-0.236	0.351
Direct Laser Deposition	0.545	-0.321	0.224
Isostatic Technology	0.545	-0.405	0.140

Table 6.11: Overall Risk Adjusted Strategic Value

6.5 Component 4 Oil System Inlet Boss (Military Engine E Type)

This component belonged to a military jet engine and was a sub part of turbine casing. In the following section the results of AHP and SAM are presented.

6.5.1 AHP Results (Opportunities)

In this case friction stir welding (14%) is the most suitable technology using the AHP method. Plasma (9.5%) and rotary friction welding (9.5%) were the two technologies with the similar lowest values.

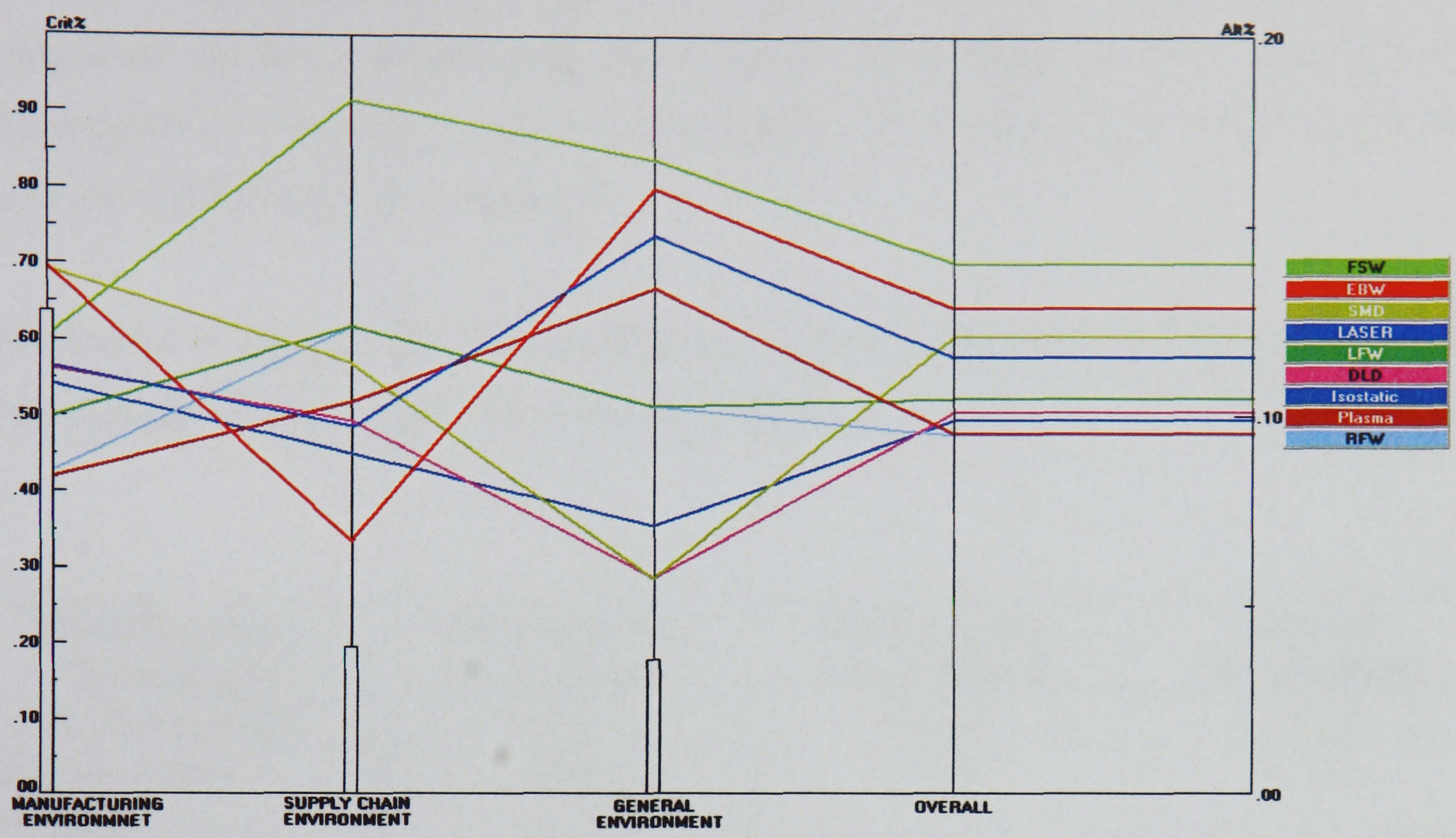

Figure 6.5: AHP Technology Performance Graph for Component 4 (Opportunities)

Name of Technology	% Contribution Towards Technology Suitability
Friction Stir Welding (FSW)	14.0 %
Electron Beam Welding (EBW)	12.8%
Shape Metal Deposition (SMD)	12.1%
Laser Welding	11.6%
Linear Friction Welding (LFW)	10.5%
Direct Laser Deposition (DLD)	10.1%
Isostatic	9.9%
Plasma	9.5%
Rotary Friction Welding (RFW)	9.5%

Table 6.12: AHP Technology Ranking Table (Opportunities)

6.5.2 SAM Results

From table 6.13 it is clear that shaped metal deposition (0.452) was the most favoured technology in the manufacturing environment opportunities. In the supply chain environment (0.148) and in general environment (0.127) friction stir welding was the most favoured technology alternative.

The winner at the end after the calculations for overall risk adjusted strategic value was shaped metal deposition (0.414) as shown in table 6.14.

Manufacturing Technology	Manufacturing Environment	Supply Chain Environment	General Environment
Laser Technology	0.416	0.106	0.112
Electron Beam Welding	0.444	0.090	0.120
Plasma Technology	0.324	0.124	0.104
Linear Friction Welding	0.358	0.127	0.098
Rotary Friction Welding	0.299	0.127	0.098
Friction Stir Welding	0.330	0.148	0.127
Shaped Metal Deposition	0.452	0.125	0.073
Direct Laser Deposition	0.396	0.119	0.073
Isostatic Technology	0.391	0.118	0.081

Table 6.13: Risk Adjusted Strategic Value (Opportunities)

Manufacturing Technology	Overall Risk Adjusted Opportunity Value	Overall Risk Adjusted Threat Value	Overall Risk Adjusted Strategic Value
Laser Technology	0.634	-0.331	0.303
Electron Beam Welding	0.654	-0.274	0.380
Plasma Technology	0.552	-0.186	0.366
Linear Friction Welding	0.583	-0.273	0.310
Rotary Friction Welding	0.524	-0.288	0.236
Friction Stir Welding	0.605	-0.398	0.207
Shaped Metal Deposition	0.650	-0.236	0.414
Direct Laser Deposition	0.588	-0.321	0.267
Isostatic Technology	0.590	-0.405	0.185

Table 6.14: Overall Risk Adjusted Strategic Value

6.6 Component 5 Igniter Boss (Military Engine A Type)

This component belonged to a military jet engine and is a sub part of the combustion chamber. In the following section AHP and SAM results are described using the significant numbers from the detailed calculations presented in Appendix H.

6.6.1 AHP Results (Opportunities)

From table 6.15 it is clear that friction stir welding (14%) is the most desirable technology alternative with plasma (9.2%) being the last on the list of available technology alternatives.

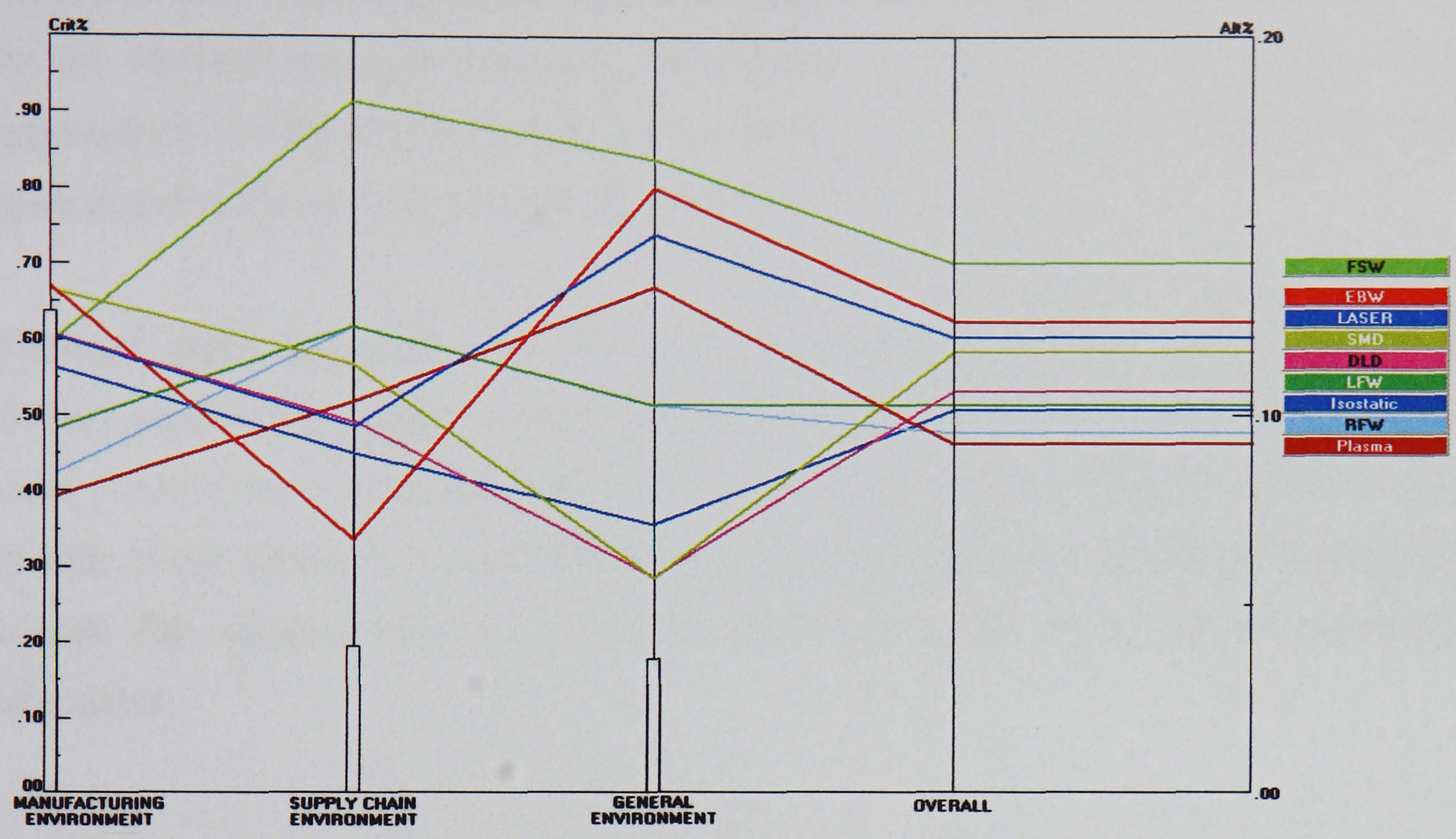

Figure 6.6: AHP Technology Performance Graph for Component 5 (Opportunities)

Name of Technology	% Contribution Towards Technology Suitability
Friction Stir Welding (FSW)	14.0 %
Electron Beam Welding (EBW)	12.5%
Laser Welding	12.1%
Shape Metal Deposition (SMD)	11.7%
Direct Laser Deposition (DLD)	10.6%
Linear Friction Welding (LFW)	10.3%
Isostatic	10.1%
Rotary Friction Welding (RFW)	9.5%
Plasma	9.2%

Table 6.15: AHP Technology Ranking Table (Opportunities)

6.6.2 SAM Results

Table 6.16 shows that laser technology (0.468) is the most suitable technology alternative for the manufacturing environment opportunities. In the case of the supply chain environment (0.148) and the general environment (0.127) friction stir welding was once again ahead of the other technology alternatives.

Although laser technology had the highest overall risk adjusted opportunity value (0.686), as shown in table 6.17, at the same time it had a high overall risk adjusted threat value (-0.331) that contributed negatively towards its overall risk adjusted strategic value (0.355). From table 6.17 it is evident that shaped metal deposition (0.424) had the highest overall risk adjusted strategic value and thus it was the most desired technology alternative.

Manufacturing Technology	Manufacturing Environment	Supply Chain Environment	General Environment
Laser Technology	0.468	0.106	0.112
Electron Beam Welding	0.453	0.090	0.120
Plasma Technology	0.328	0.124	0.104
Linear Friction Welding	0.355	0.127	0.098
Rotary Friction Welding	0.295	0.127	0.098
Friction Stir Welding	0.331	0.148	0.127
Shaped Metal Deposition	0.462	0.125	0.073
Direct Laser Deposition	0.446	0.119	0.073
Isostatic Technology	0.434	0.118	0.081

Table 6.16: Risk Adjusted Strategic Value (Opportunities)

Manufacturing Technology	Overall Risk Adjusted Opportunity Value	Overall Risk Adjusted Threat Value	Overall Risk Adjusted Strategic Value
Laser Technology	0.686	-0.331	0.355
Electron Beam Welding	0.663	-0.274	0.389
Plasma Technology	0.556	-0.186	0.370
Linear Friction Welding	0.580	-0.273	0.307
Rotary Friction Welding	0.520	-0.288	0.232
Friction Stir Welding	0.606	-0.398	0.208
Shaped Metal Deposition	0.660	-0.236	0.424
Direct Laser Deposition	0.638	-0.321	0.317
Isostatic Technology	0.633	-0.405	0.228

Table 6.17: Overall Risk Adjusted Strategic Value

6.7 Component 6 Cabin Air Boss (Military Engine A Type)

This component belonged to a military jet engine and is a sub part of the combustion chamber. Significant numbers showing technology trends using AHP and SAM are presented below.

6.7.1 AHP Results (Opportunities)

Once again from figure 6.7 it is clear that friction stir welding (16.2%) is the most desirable technology whereas isostatic (8.9%) is the least desirable among all the available technology alternatives.

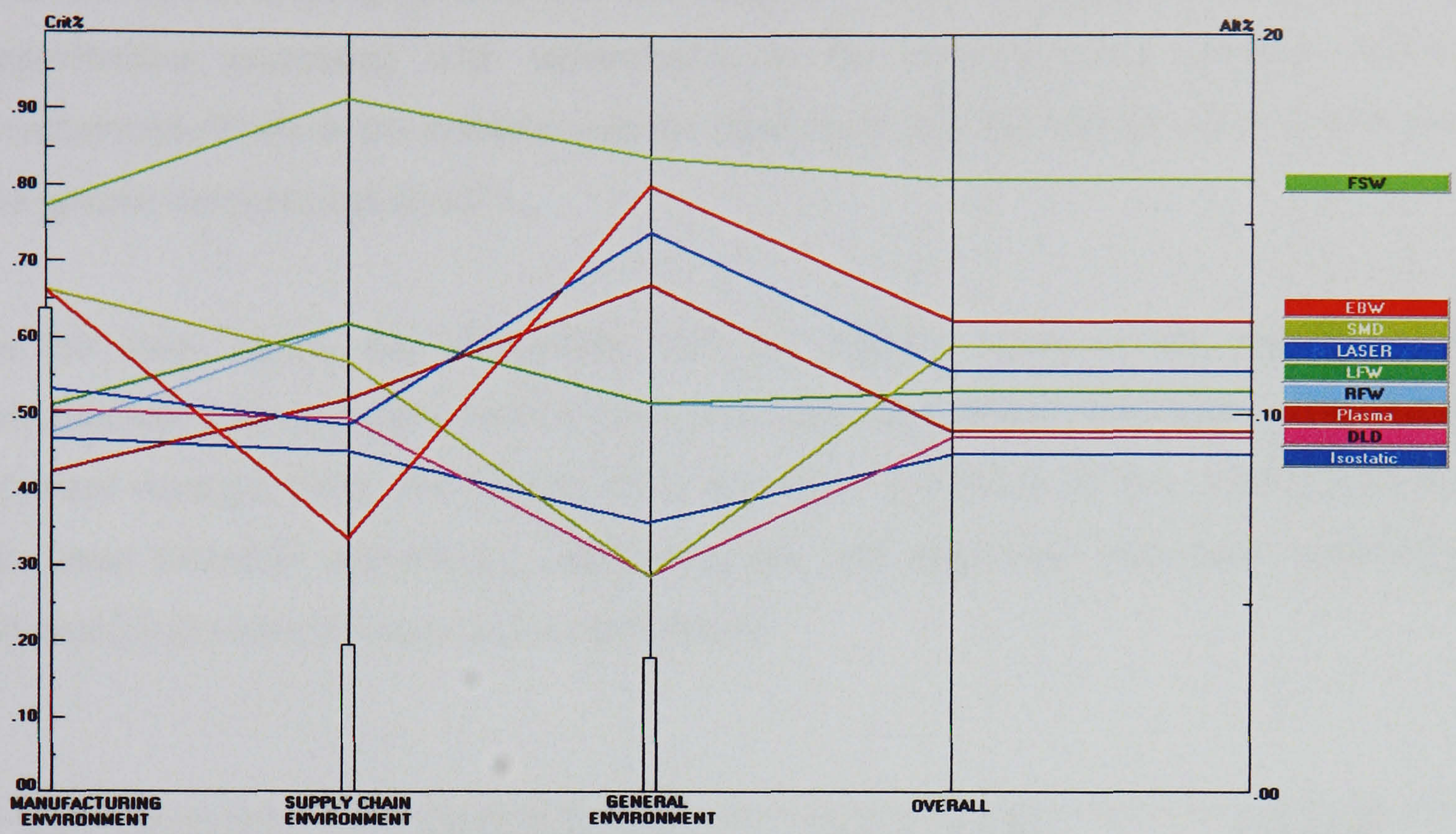

Figure 6.7: AHP Technology Performance Graph for Component 6 (Opportunities)

Name of Technology	% Contribution Towards Technology Suitability
Friction Stir Welding (FSW)	16.2 %
Electron Beam Welding (EBW)	12.4%
Shape Metal Deposition (SMD)	11.7%
Laser Welding	11.1%
Linear Friction Welding (LFW)	10.6%
Rotary Friction Welding (RFW)	10.1%
Plasma	9.5%
Direct Laser Deposition (DLD)	9.4%
Isostatic	8.9%

Table 6.18: AHP Technology Ranking Table (Opportunities)

6.7.2 SAM Results

Electron beam welding (0.420) was the most favoured technology when considering opportunities associated with technologies in the manufacturing decision making environment. Friction stir welding was the most desired in the supply chain (0.148) and the general environment (0.127).

In this case, again, the technology with the highest value in the manufacturing environment opportunities (electron beam welding) failed to have the highest overall risk adjusted strategic value, and shaped metal deposition (0.364) as shown in table 6.20 was the most desirable technology, considering the risk associated with each technology alternative in terms of opportunities and threats.

Manufacturing Technology	Manufacturing Environment	Supply Chain Environment	General Environment
Laser Technology	0.360	0.106	0.112
Electron Beam Welding	0.420	0.090	0.120
Plasma Technology	0.316	0.124	0.104
Linear Friction Welding	0.361	0.127	0.098
Rotary Friction Welding	0.335	0.127	0.098
Friction Stir Welding	0.363	0.148	0.127
Shaped Metal Deposition	0.402	0.125	0.073
Direct Laser Deposition	0.356	0.119	0.073
Isostatic Technology	0.351	0.118	0.081

Table 6.19: Risk Adjusted Strategic Value (Opportunities)

Manufacturing Technology	Overall Risk Adjusted Opportunity Value	Overall Risk Adjusted Threat Value	Overall Risk Adjusted Strategic Value
Laser Technology	0.578	-0.331	0.247
Electron Beam Welding	0.630	-0.274	0.356
Plasma Technology	0.544	-0.186	0.358
Linear Friction Welding	0.586	-0.273	0.313
Rotary Friction Welding	0.560	-0.288	0.272
Friction Stir Welding	0.638	-0.398	0.240
Shaped Metal Deposition	0.60	-0.236	0.364
Direct Laser Deposition	0.548	-0.321	0.227
Isostatic Technology	0.550	-0.405	0.145

Table 6.20: Overall Risk Adjusted Strategic Value

6.8 Component 7 HP3 Cooling Air Boss (Military Engine E Type)

This part belonged to a military engine and is a sub part of the turbine casing. In the tables below calculations from AHP and SAM are summarised.

6.8.1 AHP Results (Opportunities)

Friction stir welding (15.2%) was the most favoured technology while plasma (9.5%) was the least desirable among the set of available technologies.

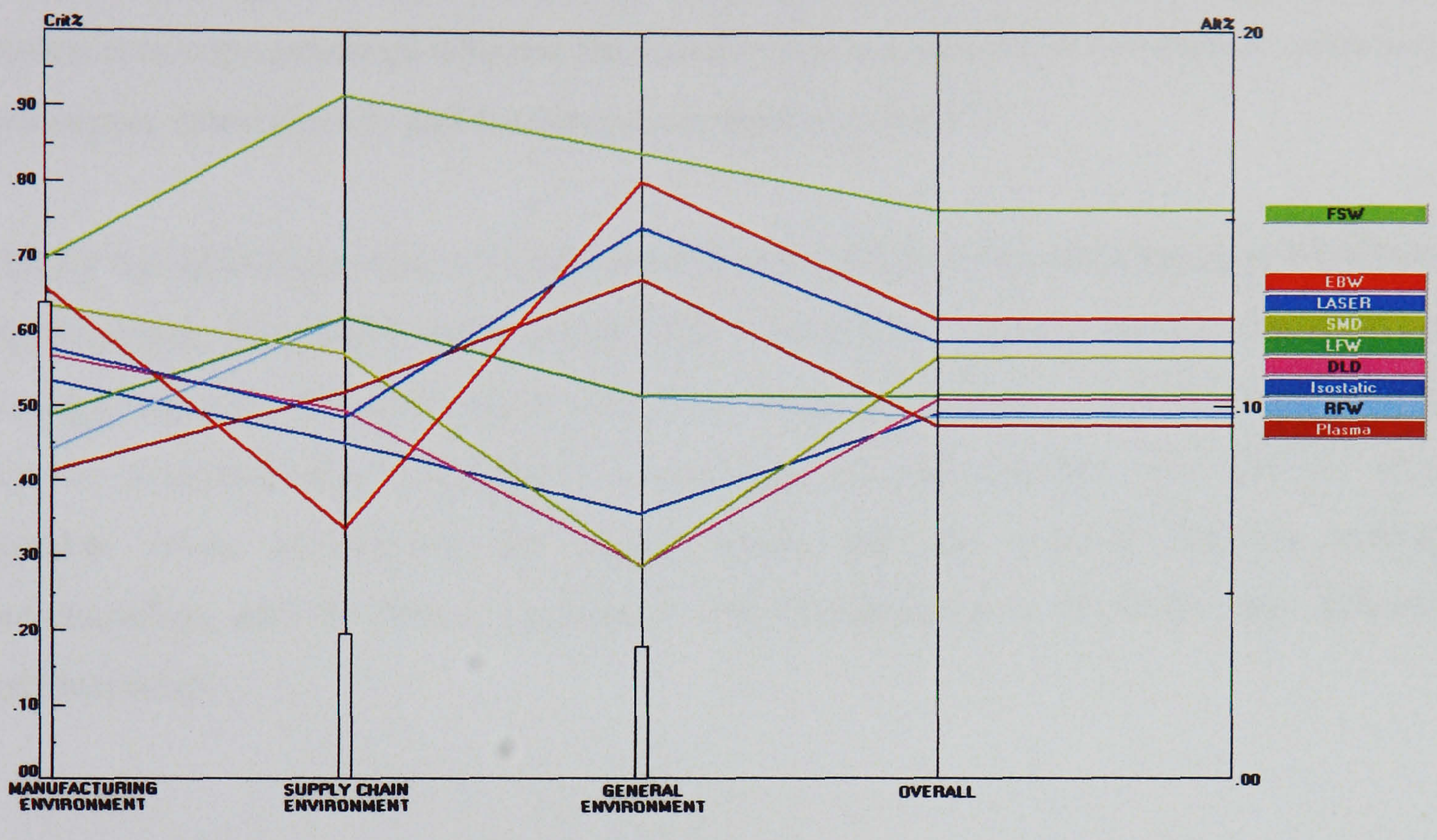

Figure 6.8: AHP Technology Performance Graph for Component 7 (Opportunities)

Name of Technology	% Contribution Towards Technology Suitability
Friction Stir Welding (FSW)	15.2 %
Electron Beam Welding (EBW)	12.3%
Laser Welding	11.7%
Shape Metal Deposition (SMD)	11.3%
Linear Friction Welding (LFW)	10.3%
Direct Laser Deposition (DLD)	10.2%
Isostatic	9.8%
Rotary Friction Welding (RFW)	9.7%
Plasma	9.5%

Table 6.21: AHP Technology Ranking Table (Opportunities)

6.8.2 SAM Results

Shaped metal deposition (0.428) was the most suitable technology for the manufacturing environment opportunities whereas friction stir welding was the most wanted technology in a supply chain (0.148) and the general environment (0.127).

Finally the technology that offered the most promise in the manufacturing environment opportunities i.e. shaped metal deposition attained the highest overall risk adjusted strategic value (0.390) as shown in table 6.23. Thus the technology that was most suitable for the manufacturing environment, considering the opportunities, was also the most suitable when considering the supply chain and the general decision making environments and the threats associated with technologies in all these three different environments.

Manufacturing Technology	Manufacturing Environment	Supply Chain Environment	General Environment
Laser Technology	0.403	0.106	0.112
Electron Beam Welding	0.420	0.090	0.120
Plasma Technology	0.321	0.124	0.104
Linear Friction Welding	0.357	0.127	0.098
Rotary Friction Welding	0.322	0.127	0.098
Friction Stir Welding	0.364	0.148	0.127
Shaped Metal Deposition	0.428	0.125	0.073
Direct Laser Deposition	0.390	0.119	0.073
Isostatic Technology	0.382	0.118	0.081

Table 6.22: Risk Adjusted Strategic Value (Opportunities)

Manufacturing Technology	Overall Risk Adjusted Opportunity Value	Overall Risk Adjusted Threat Value	Overall Risk Adjusted Strategic Value
Laser Technology	0.620	-0.331	0.289
Electron Beam Welding	0.630	-0.274	0.356
Plasma Technology	0.549	-0.186	0.363
Linear Friction Welding	0.582	-0.273	0.309
Rotary Friction Welding	0.547	-0.288	0.259
Friction Stir Welding	0.639	-0.398	0.241
Shaped Metal Deposition	0.626	-0.236	0.390
Direct Laser Deposition	0.582	-0.321	0.261
Isostatic Technology	0.581	-0.405	0.176

Table 6.23: Overall Risk Adjusted Strategic Value

6.9 Comparison between Manufacturing Environment Opportunities Values and Overall Risk Adjusted Strategic Value

In order to understand the significance of dividing the decision making environment into manufacturing, supply chain and general environment a comparison between the highest manufacturing environment opportunities value and the highest overall risk adjusted strategic value calculated by using SAM in the above section for each of the seven components are presented in table 6.24. The values are taken from the manufacturing environment opportunities for the comparison with the overall risk adjusted strategic values because of the reason that the technology managers at the aerospace manufacturing company were more accustomed to making decisions regarding their technology selection issues by just considering their own manufacturing needs. Moreover they were more familiar with technology selection by keeping in view only the opportunities available with each of the available technology alternatives. This is the existing technology selection decision making practice at the company and the results obtained using this approach are shown in table 6.24 in the column titled manufacturing environment (opportunities). The comparison between the highest manufacturing environment opportunity value and the overall risk adjusted strategic value is used to demonstrate both the role of threats associated with technology alternatives and inter-organisational factors in the technology selection process. The active role of threats and inter-organisational factors in the technology selection decision making process is confirmed by the difference between the technology manufacturing environment opportunity value and the technology overall risk adjusted strategic value.

Engine Component	Manufacturing Environment (Opportunities)	Overall Risk Adjusted Strategic Value
Component 1	0.432 Friction Stir Welding	0.360 Plasma
Component 2	0.505 Shaped Metal Deposition	0.467 Shaped Metal Deposition
Component 3	0.403 Electron Beam Welding	0.359 Plasma
Component 4	0.452 Shaped Metal Deposition	0.414 Shaped Metal Deposition
Component 5	0.468 Laser	0.424 Shaped Metal Deposition
Component 6	0.420 Electron Beam Welding	0.364 Shaped Metal Deposition
Component 7	0.428 Shaped Metal Deposition	0.390 Shaped Metal Deposition

Table 6.24: Manufacturing Environment and Overall Risk Adjusted Strategic Values

From table 6.24 it is clear that component 1, 3, 5 and 6 had different technology rankings in the manufacturing environment opportunities and in the overall risk adjusted strategic values. This shows that other environmental factors i.e. supply chain and general have influenced the technology selection process and the threats associated with the technologies in the three decision making environments have also been decisive in the technology evaluation process. In other words this depicts the importance of the different decision making environments in the technology selection process and also advocates the importance of identifying both the opportunities and threats for all the available technology alternatives.

6.10 Explanation of Difference between AHP and SAM Results

The difference in results using the AHP and SAM methodology in this research can be perplexing. AHP was employed in this research to identify the detail characteristics associated with each technology alternative in the context of step 5 of the technology selection framework as described in detail in Chapter 4. It provided the flexibility to carry out the 'what if' analysis if any of the decision making criteria changes and that helped in the data collection phase of this research as the visual graphics of AHP helped to engage the technology managers. Importantly, one of the inputs to the SAM methodology is subjective weights and that was achieved by using AHP. While carrying out the subjective weight calculations exercise with the technology managers it was decided to utilise the opportunity to carry out the full technology evaluation using AHP as it proved to be a useful exercise in educating the technology managers about the technology selection process and to find out about the concerns and apprehensions of the technology mangers regarding the evaluation of their technologies. It provided a set of data that is compared in the earlier sections with the SAM results for each of the seven engine components. However the purpose of this data comparison is just to understand the decision making process and the final results for the technology evaluation in this research are based on the SAM methodology as described in detail in Chapter 4.

SAM considers both the subjective weights and the risk-aversion factors for each opportunity and threat. Let us consider a simple problem of purchasing a car. Car-A and Car-B are the alternative choices and two factors: purchase price and expected repair costs during the life of the car are the criteria (factors):

	Car-A	Car-B
Price	£1000	£2000
Repair Costs	£800	£200

It is clear that both factors are minimising, meaning that 'the smaller, the better they are'. Car-A is cheaper but more expensive to repair while Car-B is more expensive but cheaper to repair. A decision maker might consider the price more important than the repair costs and assigns 70% importance weight to the price and only 30% importance weight to the repair costs. This is a simple multi-criteria decision making (MCDM) problem in decision theory. In SAM, the pound values are actually replaced by probabilities of occurrence. These probabilities of occurrence, just like the pound values, are used to measure the performance of each factor on each alternative. The subjective weights in this example do not consider and are not reflective of any risks. In other words, the decision maker might believe that the price is more important than the repair costs but how much risk is he or she willing to take on each factor. The decision maker might rationalise that the price is known, one car is £1000 and the other car is £2000. Therefore, there is very little risk in the price (unless a seller changes his or her mind) but the repair costs of £800 and £200 are just 'estimates' and could potentially be very different. In other words, the repair costs are riskier. The risk-aversion factor in SAM is intended to capture this risk. Risky factors are given a higher risk-aversion factor while less risky factors are given a smaller risk-aversion factor.

In short the difference in AHP and SAM can be summarised as:

1. AHP analysis throughout uses the concept of relative weight for calculations. Whereas SAM uses the concept of probability of occurrence of factors rather than relative weights of the factors.

2. SAM uses a series of analytical techniques to calculate the overall importance weight for opportunities and threats whereas in AHP analysis it is again calculated using the relative weight methods.

3. In SAM a risk aversion constant for opportunities and threats have been assigned. The risk aversion constant is calculated for each opportunity and threat by using certainty equivalence and if the decision maker is risk averse for a particular opportunity or threat then a high risk aversion value is assigned for that factor. Similarly if the decision maker is risk neutral then a low risk aversion value is assigned. In case of AHP analysis there is no measurement with respect to risk associated with each of the opportunities and threats.

6.11 Existing Decision Making Process

In order to demonstrate how the technology selection framework can be helpful in making strategic decisions regarding technology alternatives, it is important to understand the current decision making process for technology selection at the company.

The product life cycle at the aerospace manufacturer can be divided into preliminary design, detail design, operations and support. The product stages in the preliminary design and the detail design phases are shown in figure 6.9. From figure 6.9 it is clear that the product life cycle starts with the preliminary design that includes an analysis of the requirement from the customer and the definition of the preliminary concept. The detail design phase involves a number of steps and concludes with the manufacturing of the desired component. The process of manufacturing technology selection for the component is performed by the technology capability acquisition group by considering the detailed manufacturing model of the product and the attributes of the existing technology alternatives. The major input to the technology acquisition group is the technical design specifications for the product and it is supposed to select the manufacturing technology that fulfils those design criteria. Cost modelling is the only business objective that has an input in the current selection of manufacturing technologies.

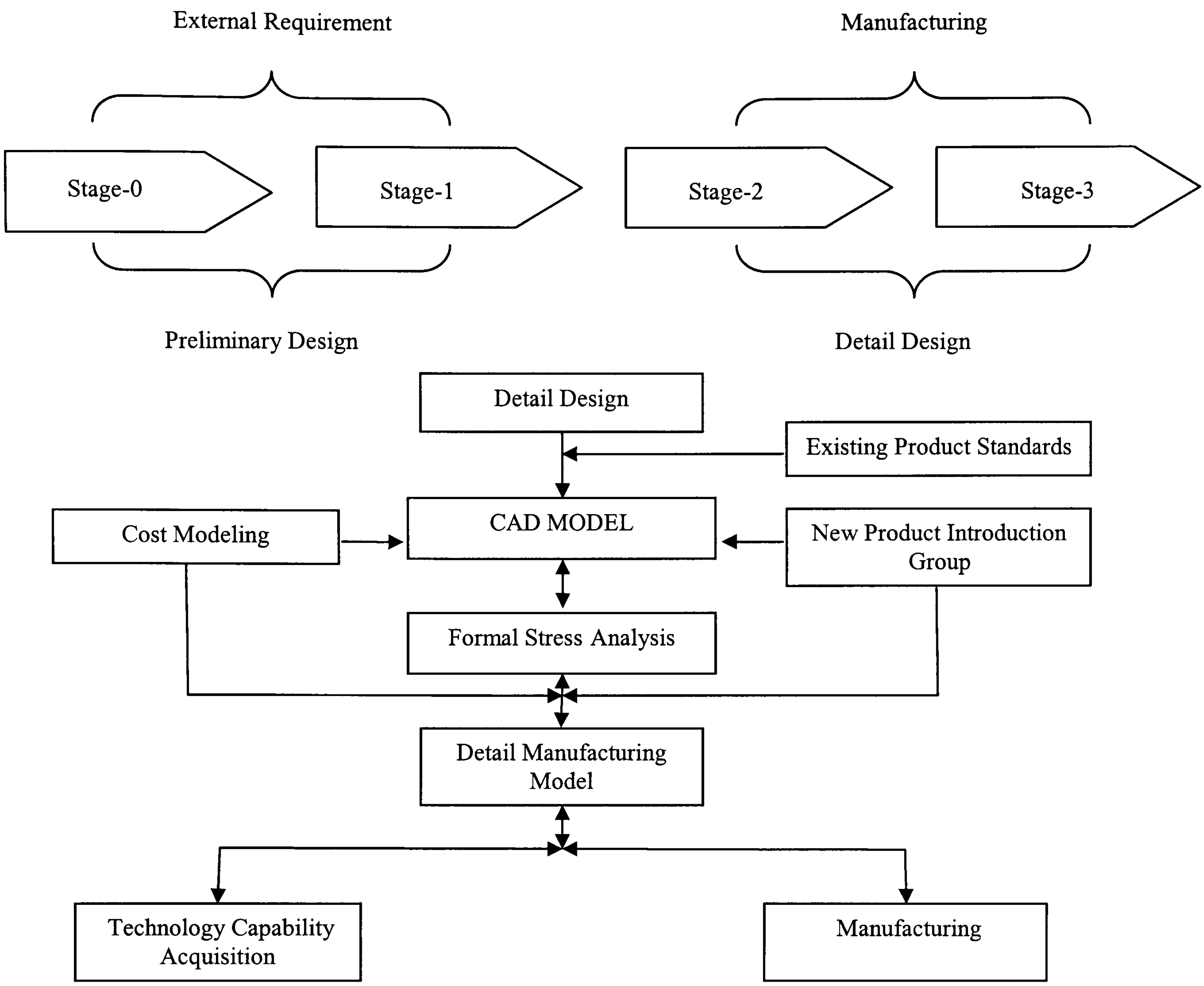

Figure 6.9: Product Life Cycle (Preliminary & Detail Design Phase)

6.12 Integration of the Technology Selection Framework with the Existing Decision Making Process

The technology selection framework developed can be integrated with the existing decision making process by using the final output of the framework as the input to the technology capability acquisition group as shown in the figure 6.10. The final output of the framework is a risk adjusted technology strategic value, a risk adjusted technology opportunity value and a risk adjusted technology threat value.

Since the technology capability acquisition group is responsible for selecting a particular technology for engine component manufacturing the final output from the technology selection framework can provide the capability acquisition group a strategic evaluation of available technology alternatives from both a manufacturing and supply chain perspective. Similarly the technology alternatives evaluation can be provided to manufacturing in order to present them with the opportunities and threats associated with the technology alternative in three decision making environments (manufacturing, supply chain and general) so that they completely understand the evaluation process of the selected technology and can play a greater role in achieving the overall business objective of the company.

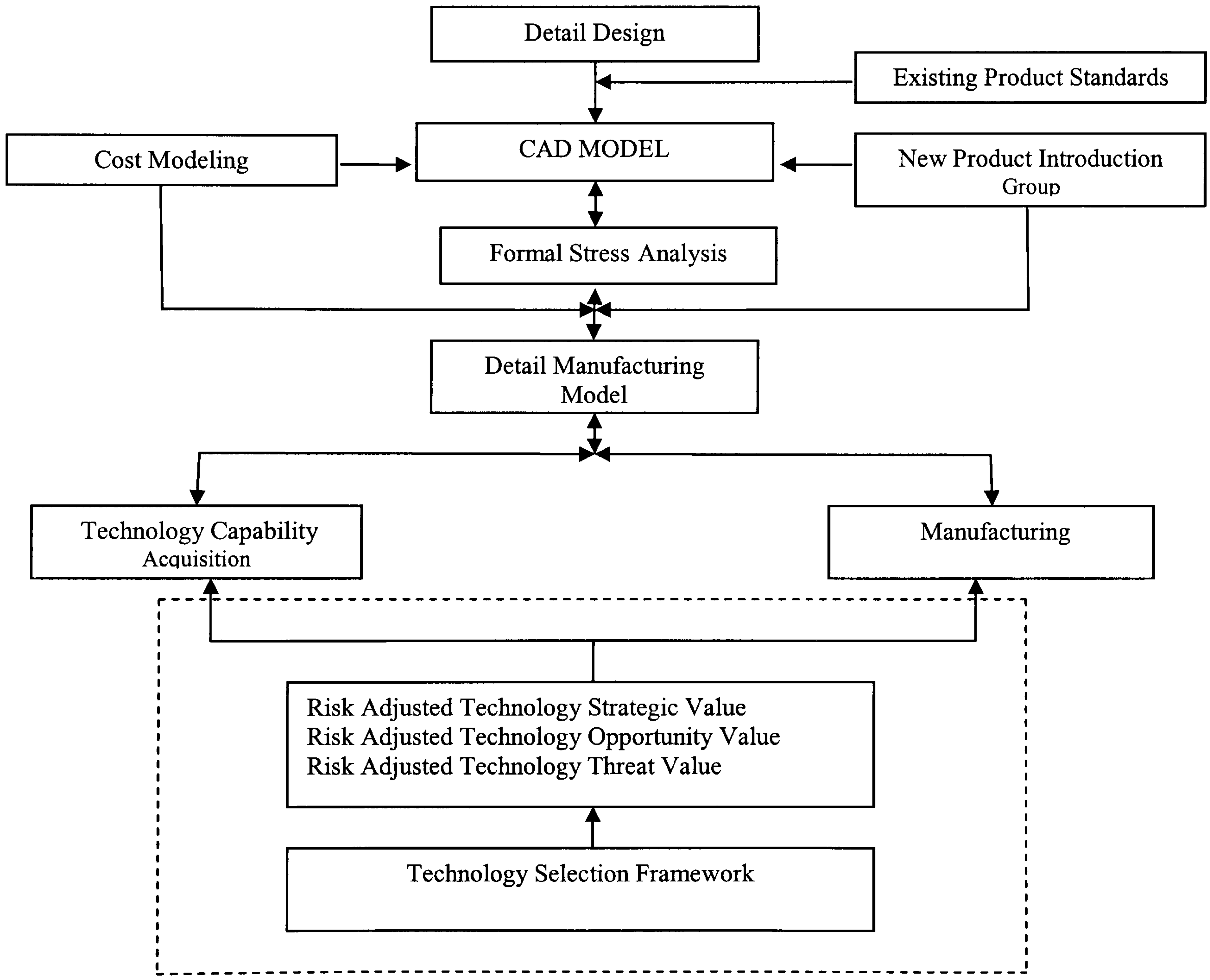

Figure 6.10: Integration of Technology Selection Framework with Existing Process

6.13 Usefulness of Technology Selection Framework

The usefulness of the technology selection framework in the context of the aerospace manufacturing company is explained by looking at the aerospace company operational excellence model. For this we have to consider first the aerospace production system.

6.13.1 Aerospace Company Production System

The aerospace company production system is shown in the figure 6.11. It consists of the following constituent components:

- Total Equipment Management
- Industrial Engineering
- Product Introduction
- Quality Management Systems
- Factory Design & Layout
- Production Planning & Control
- Supply Chain Management

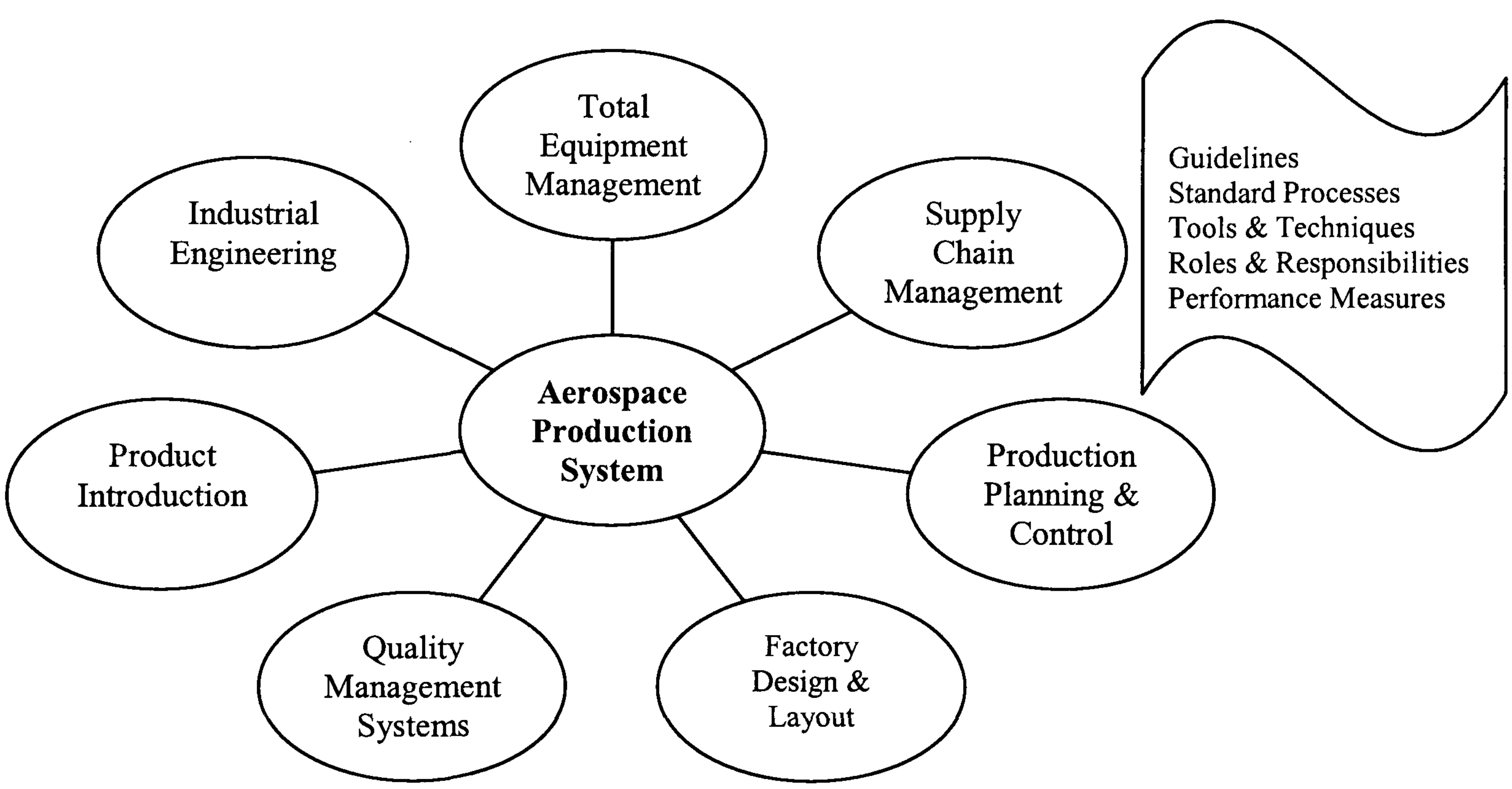

Figure 6.11: Aerospace Production System

The defined set of production system needs guidelines, processes, tools and techniques for the implementation of the production system. In order to support the production system an operational excellence plan shown in figure 6.12 is devised that contributes towards the successful execution and implementation of the production system.

6.13.2 Aerospace Operational Excellence Model

The operational excellence model (figure 6.12) consists of three major segments namely:

- Consolidation
- Growth
- Future Development

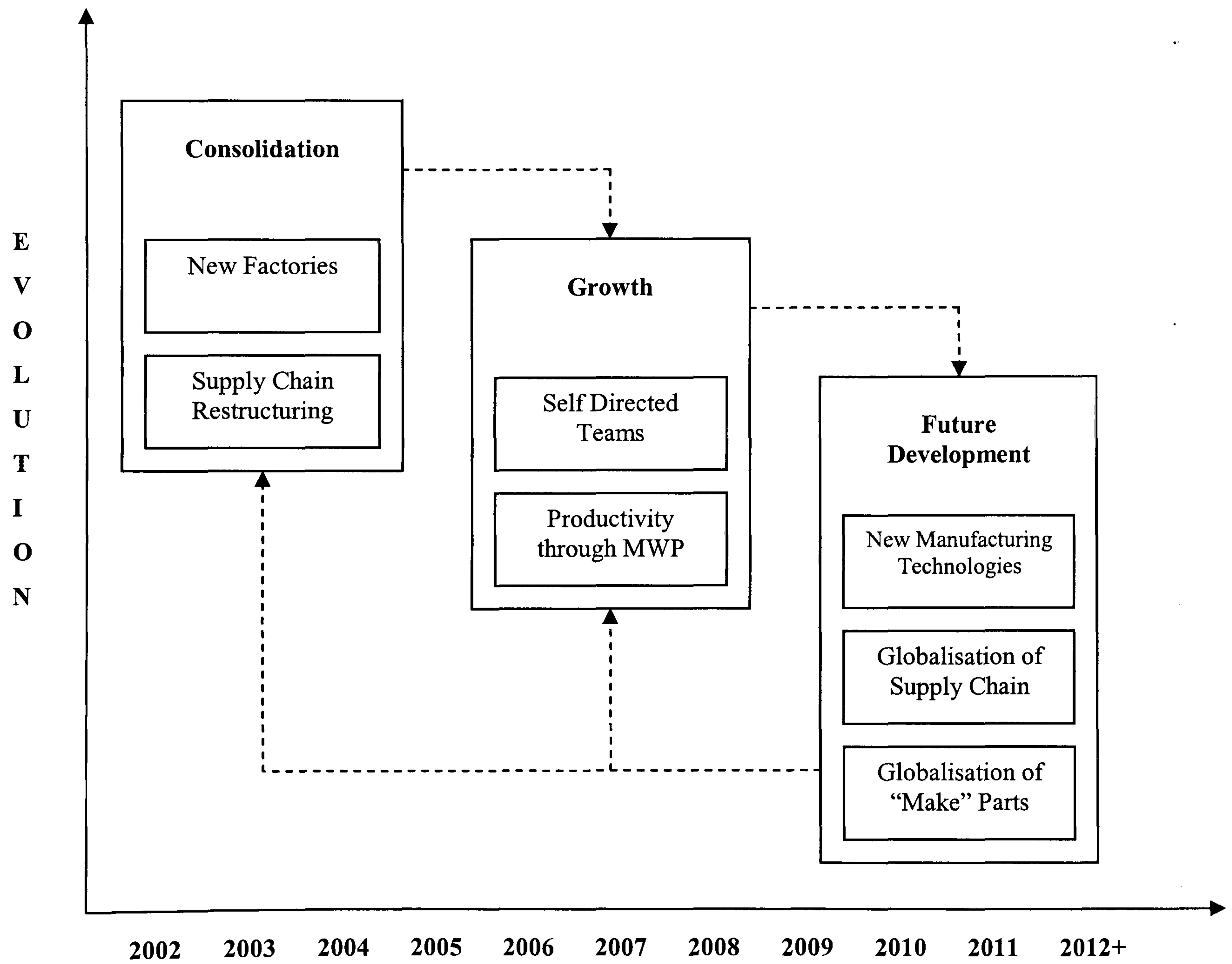

Figure 6.12: Aerospace Operational Excellence Model

a. Consolidation

The consolidation process consists of new factories and supply chain re-structuring. New factories are established on the principle of simple focused layouts based on flow with dedicated machines arranged for operations. Supply chain re-structuring consisted of aligning and consolidating the supplier base. Traditionally the different business units (fans, compressors, combustion, turbine and controls) were having a number of suppliers resulting in the shape of supply chain shown in figure 6.13. The process of supply chain re-structuring involves identification of key suppliers in order to simplify the supply chain as shown in figure 6.14. Another important purpose of supply chain re-structuring was to develop a risk and revenue sharing scheme with the identified key suppliers.

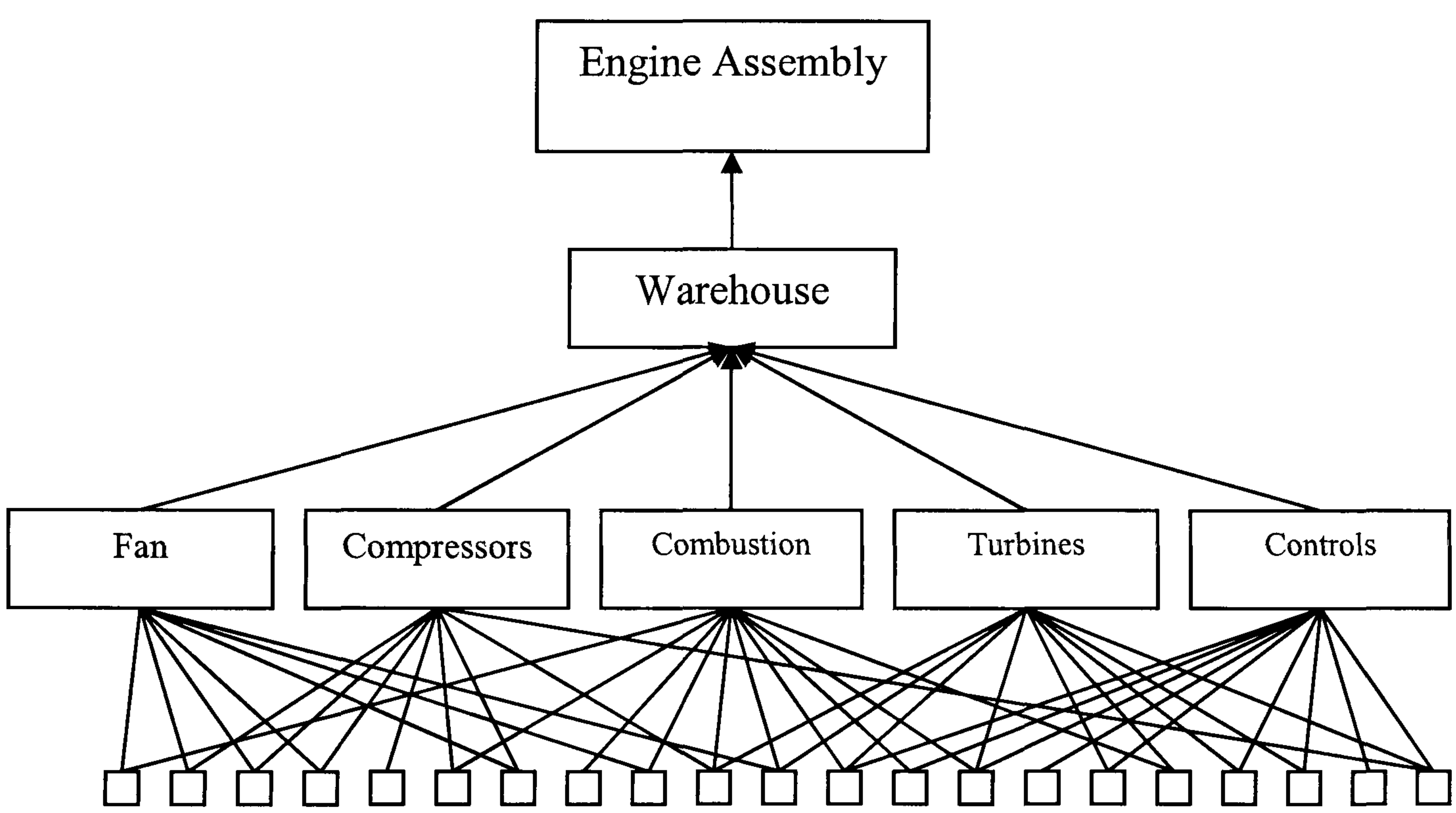

Figure 6.13: Traditional Supply Chain

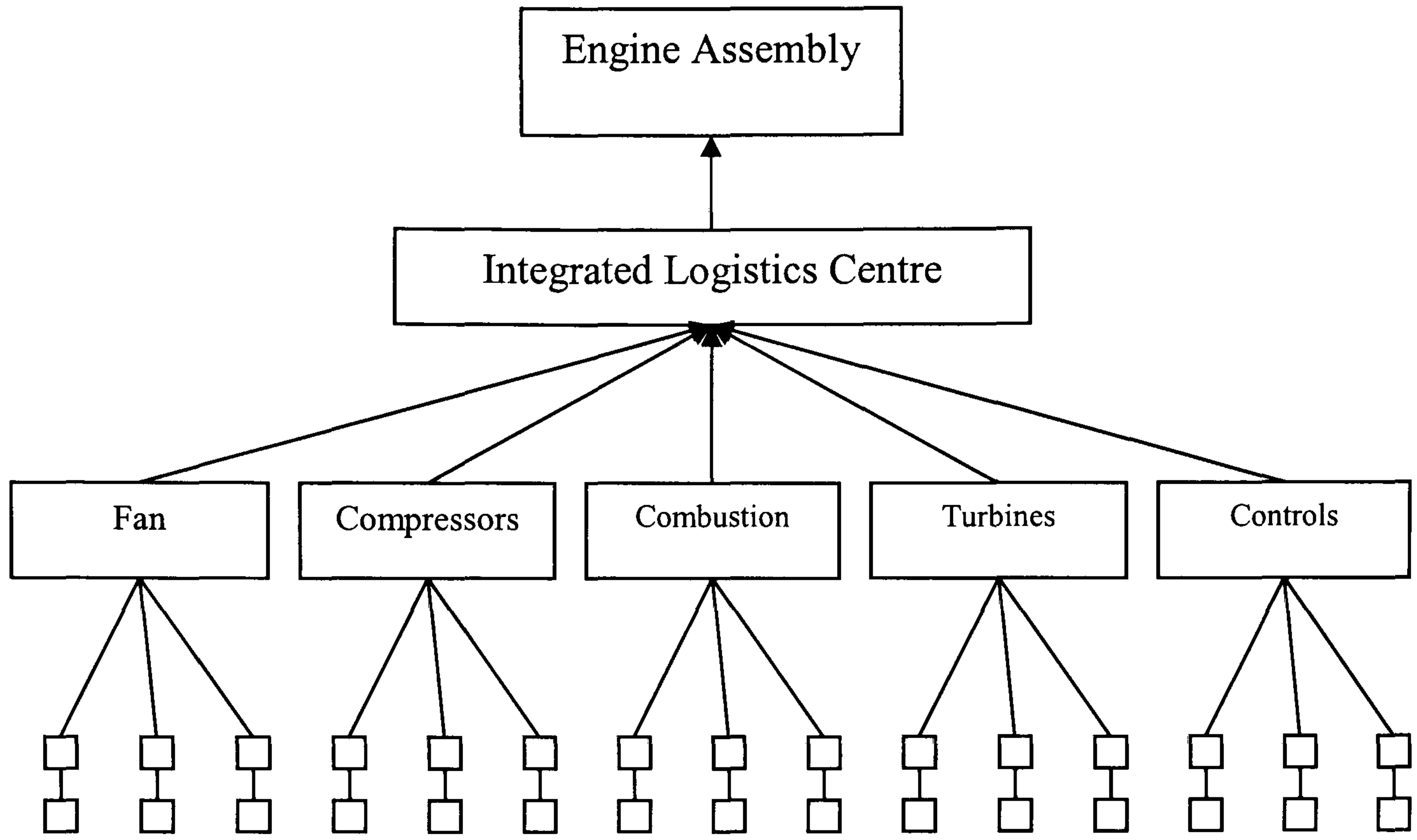

Figure 6.14: Future Supply Chain

b. Growth

Growth comprised of self directed teams and productivity through modern working practices. Self directed teams and modern working practices included a multi skilled workforce, greater shift flexibility, single status working, all inclusive pay structure, flow line manufacturing and output based incentives.

c. Future Development

Identification of new manufacturing technologies, globalisation of supply chains and globalisation of make parts are some of the important aspects of future development. This means the company plans to continuously identify the new emerging technologies and do realise that it has to brace the globalisation of not only its supply chains but also the globalisation of 'make parts'.

6.13.3 Operational Excellence Model and the Technology Selection Framework

It is clear from figure 6.12 that the immediate future development (Year 2009-2012) in the aerospace company will address the new manufacturing technologies, globalisation of supply chains and globalisation of make parts. The identification of new manufacturing technologies is critical to the success of the company as it is the source of their competitive advantage. Similarly the company is consolidating its supplier base resulting in fewer selected suppliers across the globe and having the risk and revenue supply partnership with the fewer dependable selected suppliers. With every passing day more and more make parts are either outsourced to the global suppliers or they are becoming buy parts. Thus the manufacturing of the aerospace company is heavily dependent on its supply chain for the timely manufacturing of different engine components. Therefore the aerospace company requires tools and techniques that incorporate the state of supply partners while considering key inter-organisational as well as intra-organisational decisions. Considering this, the research considers manufacturing technology selection as an intra-organisational decision for the aerospace company and presents a technology selection framework that combines not only intra but inter-organisational factors by dividing the decision making environment into manufacturing, supply chain and general environments.

6.14 Conclusion

Considering the figure 6.15 it is evident that the technology selection framework integrates the downstream and upstream supply chain with manufacturing. The downstream side of the supply chain is customer facing and it dictates to manufacturing about the needs of the customer and consistently monitors the market competition. On the other hand the upstream side takes care of the raw material suppliers. In between the two sides of the supply chain rests manufacturing. In the technology selection framework evaluation of the supply chain, critical supply chain factors for competition and time horizon presents information based not only on organisational needs but also by considering the inter-organisational perspective. Similarly while selecting manufacturing technology alternatives using the framework the decision making environment is divided into three consisting of manufacturing, supply chain and general environments. The manufacturing environment considers the manufacturing opportunities and threats that comprise mostly of intra-organisational factors, whereas the supply chain environment considers opportunities and threats associated with the manufacturing technology alternative from an inter-organisational view. Thus as the aerospace manufacturer is now about to enter in the era of globalised supply chains as described in figure 6.12 and with the introduction of new manufacturing technologies the technology selection framework presents an analytical and systematic approach to the company to decide about its current as well as future manufacturing technologies by considering the changing shape of global business environment in the form of extended supply chains.

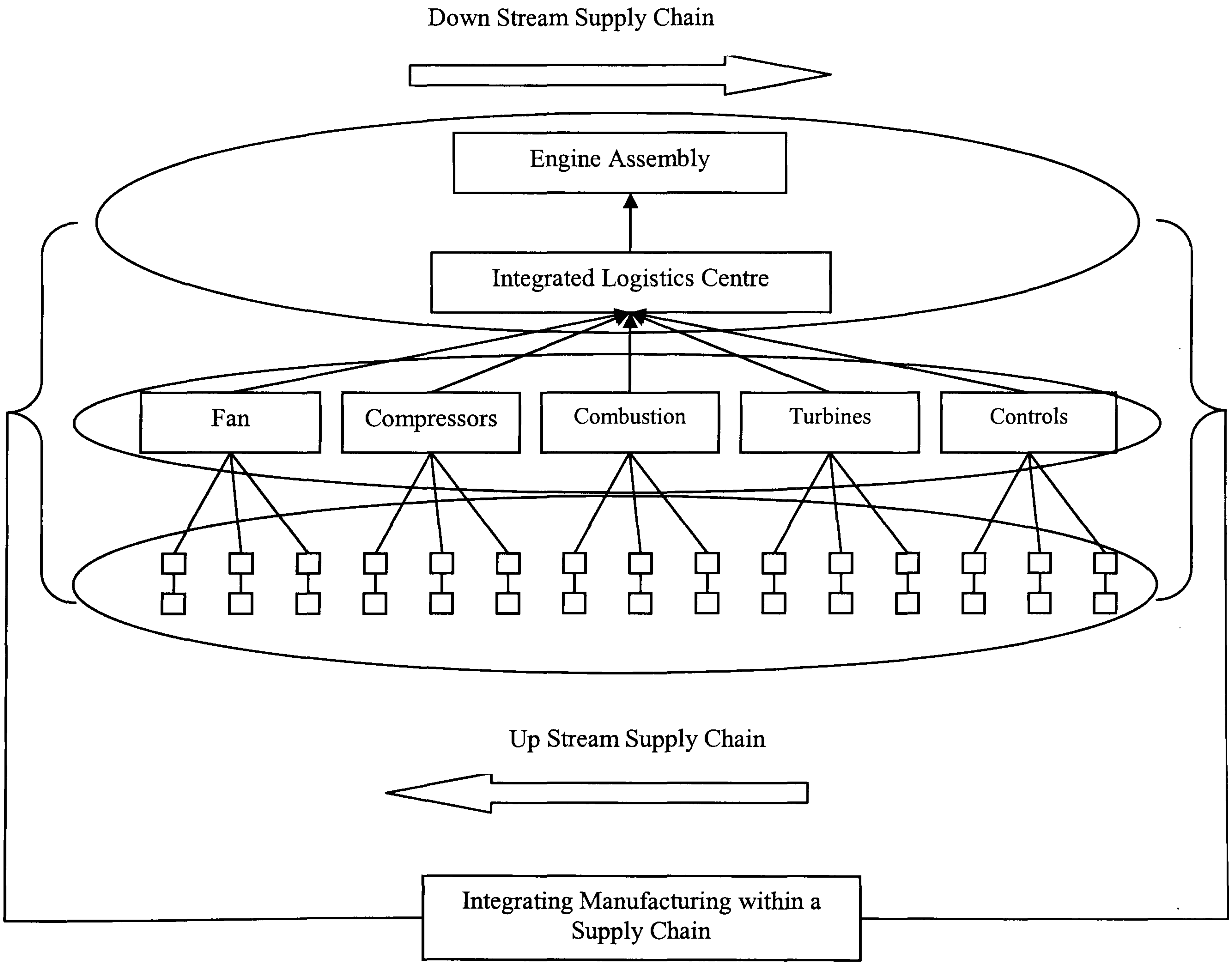

Figure 6.15: Integrating Manufacturing within a Supply Chain

In this chapter the results of the technology selection process in the aerospace manufacturer are presented in detail. The difference in results using the AHP and SAM method are explained and the risk adjusted strategic value for each technology alternative considering each engine component for manufacturing is documented. The chapter describes the integration of the proposed technology selection framework with the existing decision making process. The usefulness of the technology selection framework in the context of the manufacturer's production system is explained by the help of an aerospace operational excellence model. The next chapter will establish a link between the research lessons from this case study and the research objectives that were defined in the Chapter 1. The limitations of this research and future research directions are also explained in the following chapter.

Chapter 7

Discussion and Conclusion

7.1 Introduction

This chapter summarises the research findings and describes the research contributions to academia and industry. The research aims and objectives defined at the start of the study are reviewed again from a perspective of linking them with the experience and results gained during the research. The limitations of this research are also presented in this chapter. Finally, possibilities for improving this research and directions for future research are documented.

7.2 Research Approach

A technology selection framework was developed keeping in mind the research questions described in Chapter 1. The main aim of the technology selection framework was:

- Inclusion of the Supply Chain in the Technology Selection Process
- Operationalisation of the Technology Selection Process
- Role of Risk Evaluation in Strategic Technology Selection

Considering the empirical nature of this research it was decided to conduct a detailed study in an organisation where technology selection was a major area of decision making. Furthermore it was important to select an organisation with an established supply chain and where supply chain played an important role in the success of the company as the purpose of the study was to include the supply chain issues in a company's technology selection process. It was deemed necessary to include people in the research from manufacturing as well as the supply chain side to have a complete picture of the organisation and to have the views and expertise from both sides. The explained pre-requisites of this research pointed towards the direction of an aerospace manufacturer for the detailed study. The aerospace manufacturer was an ideal place to carry out this research as they routinely face the challenge of technology selection in their manufacturing operations. Moreover they have established and extended supply chains with over 70% of their products either outsourced or purchased making them dependent on the performance of the supply chain to achieve their business goal. The operational excellence model of the aerospace manufacturer discussed in Chapter 6 validated the importance of new manufacturing technologies and global supply chains in the near future. The requirement of the aerospace manufacturer for the tools and techniques for integrating its manufacturing and supply chain fitted well with the overall objectives of this research. Therefore they collaborated actively during the research process.

Action research was selected as the research methodology for this study. Action research provided flexibility to impart education and be educated during the research process. Since the technology selection process was developed earlier by scanning the literature and by observing the implementation of the technology selection framework in a pilot study, therefore at first in the aerospace manufacture it was required to educate the concerned managers regarding the working of the technology selection framework. They were educated in the working of the technology selection framework and in return they educated the researcher regarding their manufacturing and supply chain operations. Thus it provided an opportunity for two way knowledge exchange. The investigation at the aerospace manufacturer involved semi- structured interviews, brainstorming sessions, qualitative and quantitative questionnaires as well as non- participant observations. The respondents were from manufacturing technology and supply chain functions as the focus of this research was about these two functions.

7.3 Research Contribution

The major objective of this research was to develop a decision making framework for manufacturing technology selection having the following salient features:

- Incorporation of Manufacturing and Supply Chain within a Technology Selection Decision Making Loop
- Linking the Content and Process sides of Manufacturing Strategy
- Identification of the Opportunities and Threats Associated with Technologies
- Risk Evaluation in Technology Selection
- Refinement of the Technology Selection Framework through Industrial Application

The research process carried out to achieve the above features resulted in the following industrial and academic contributions.

7.3.1 Industrial Contribution

The main industrial contribution of this research is the decision making framework for manufacturing technology selection keeping in view the supply chain perspective. During the course of the research it was observed and independently confirmed by the various company managers that the whole exercise of operationalising the technology selection framework contributed positively in a number of ways.

7.3.1.1 Decision Support

The basic and foremost advantage of the technology selection framework was reported to be able to achieve an objective decision on the basis of quantified results. It was appreciated the way intangible and subjective factors associated with the technology selection process were quantified using different approaches discussed in the technology selection framework and the inclusion of risk calculations in the technology evaluation process further crystallised the decision making process. The availability of a numerical analysis of different technology alternatives in three decision making environments helped technology managers to relate the evaluated results to their daily day to day key performance indices (KPI). This was mentioned by the managers while responding to the questions provided in Appendix E.

7.3.1.2 Holistic Approach to Technology Selection

A holistic approach regarding manufacturing technology selection should not only consider manufacturing objectives for technology selection but should emphasise the importance of the supply chain and consider the interdependence of manufacturing and the supply chain in the decision making process. The existing decision making process for technology selection at the aerospace manufacturer was organised on a functional basis. However the ever increasing rate of transformation of make parts into buy parts has resulted in the success of the company being heavily dependent on the performance of the supply chain. It can be noted from the supply chain performance and market evaluation of the turbine and combustion chamber provided in Chapter 5 that the areas where the supply chain of the company was struggling in providing a satisfactory service resulted in the poor performance of the product in that performance area when compared to its competitor in the market. Therefore a link between supply chain performance and the market performance of a product can be established. This demands the inclusion of supply chain issues in the areas of strategic decision making within the aerospace company. The technology selection framework was a step in that respect that provided a methodology to involve the broader issues related to the technology selection and provided a holistic approach to the technology selection decision making process. The managers remarked (Appendix E) that the technology selection framework provided a collaborative approach and can be useful for them to replicate for other intra as well as inter organisational decision making processes. The candid remarks and personal experiences of managers from the supply chain and manufacturing sides helped to develop an environment of mutual exchange of knowledge between the managers from the two sides of the business and the researcher and provided a better understanding of the different functions of the organisation for the decision making process.

7.3.1.3 Supply Chain Awareness

The role of supply chains have emerged strongly in recent decades and now every major company is having supply chain management as a core functional element in its organisational setup. Although the aerospace manufacturer boasts an integrated supply chain, the integration within the company between manufacturing and supply chain functions was found to be wanting. The technology managers in the manufacturing function seemed to be making all the decisions keeping in mind only their manufacturing requirements. When they were first asked about including supply chain considerations while making their technology selection decisions some of them said they do not select their technology like that while other simply said their lack of knowledge regarding supply chain issues is a major hindrance for carrying out the requested technology selection process. The managers were helped in brainstorming certain supply chain issues that could affect their technology selection decisions. Functional as well as holistic integration of technology selection and supply chain was explained for their active participation in the technology selection framework. The company managers conceded (Appendix E) that the process provided them a broader understanding of the issues surrounding a supply chain and they would be in a better state to recognise and address the supply chain issues in the future.

7.3.1.4 Technology Debate

The pace of technological advancement has caused the companies to consistently review and assess their manufacturing technologies so that they are aware of their technological needs and the available technology solutions. In this research the technologies used for the evaluation process were all well perceived at the aerospace manufacturer. The daily busy routine of the technology managers rarely provided them any opportunity to present their views regarding any technology. Since the technology selection framework required technology managers to prioritise their technologies and to identify opportunities and threats associated with the technologies, it provided an environment for discussion between managers to exchange their experiences of different technologies. The technology managers declared that it was a learning experience for them to listen to the concerns and views of their fellow managers regarding a machine that both of them have been using for years but have never exchanged their experiences because of their busy day to day routine. The technology selection process at least started the technology debate among the mangers.

7.3.1.5 Organisational Learning

The implementation of the technology selection framework in the aerospace manufacturer provided a revealing insight into their organisational setup. The technology selection process connected two functions of the organisation namely manufacturing and supply chain. The two functions were supposed to be seamlessly integrated however the observations during the course of this study did not support this self assumed claim of the company. The attitude of some of the technical managers towards the work of their supply chain colleagues was an interesting observation. The aerospace manufacture is a highly specialised technical organisation and the majority of the managers employed there shared a common pride in their technical expertise. It was observed that in some cases the work of people in non technical or less technical roles was not regarded with the same esteem as that of the technical roles. This provided another intriguing direction towards the organisational behaviour of different people operating in different roles who are dependent on each other for the success of a company. The experienced managers explained that the concept of supply chain and work related to its needs to be properly propagated within the organisation at all technical and non technical levels, so that the employees appreciate the role of the supply chain and contribute actively in supply chain optimisation. The company has arranged for several masters degree programmes for its managers in supply chain education at various UK universities in the recent past. This shows that they understand the need to educate their managers in supply chain concepts and they acknowledged the effort towards bridging the gap between manufacturing and the supply chain in the technology selection framework.

7.3.2 Academic Contribution

This research contributes towards the body of existing literature in technology selection decision making, manufacturing strategy and the supply chain literature.

7.3.2.1 Technology Selection Decision Making

Literature in technology selection predominantly consists of technology selection from a research and development (R&D) perspective and recently much emphasis has been on the selection of information and communication technologies (ICT). The literature addresses mainly the monetary factors in the technology selection process. Moving away from the traditional line of research in technology selection, in this research a technology selection process is introduced to select manufacturing technologies from amongst available technology alternatives by considering the supply chain perspective. The presented technology selection framework has contributed towards decision making in technology selection in the following manner.

a. Division of the Technology Selection Environment

The decision making literature advocates the division of the decision making environment for a comprehensive analysis. However few studies can be found that adopt this approach. The decision making environment for technology selection was decomposed into three environments, namely manufacturing, supply chain and general environment. The division of the technology selection environment into these three environments resulted in the detailed analysis of the available technology alternatives according to various factors defined in those three environments. The decomposition of the decision making environment helped in understanding the contribution of technologies towards manufacturing and supply chain causes separately. Therefore it was easy for the decision makers to visualise how their selected technology was affecting both their manufacturing and supply chain objectives and which technologies contributed more positively in the manufacturing environment then in the supply chain environment and vice versa. This kind of quantitative data representation aided the decision makers to make decisions objectively regarding their technology selection keeping in mind and satisfying their overall business objectives.

b. Identification of Opportunities and Threats for Technology Selection

One of the novel features of the technology selection framework was the identification of opportunities and threats associated with technology alternatives and the assessment of these alternatives in the strategic selection of the technology alternative. The introduction of the concept of opportunities and threats associated with the technologies changed the dynamics of the technology selection process. Normally the threats associated with technologies are not included in the strategic technology assessment. But as mentioned in Chapter 6, the inclusion of threats associated with technologies in the assessment method altered the final outcome of the process. Some of the technologies that were offering favourable values when considering opportunities were not ranked high after the final evaluation as they also contributed highly towards the threats associated with the technologies. Therefore their threat values negated their opportunities values and they were not able to achieve a higher ranking in the final assessment. This indicated that it is recommended to consider the threats along with the opportunities while making key decisions regarding technology selection.

c. Risk Calculations for Technology Selection

The selection of an alternative cannot be completed without evaluating the risk associated with all the available alternatives. The inclusion of risk calculation of the opportunities and threats associated with technology alternatives provided comprehensiveness to the process of strategic assessment of the technology alternatives. The literature highlights the importance of risk calculations in the technology selection process but to the researchers knowledge it does not provide any methodology or framework to incorporate risk in the technology selection decision making problem. The risk calculations showed the attitude of decision makers towards opportunities and threats as they attributed high risk aversion values to the opportunities and threats towards which they were more sensitive and provided lower risk aversion values to opportunities and threats towards which they were less concerned thus exposing their mental perceptions while making decisions regarding technology selection.

7.3.2.2 Process Side of Manufacturing Strategy

The literature on manufacturing strategy is always guiding towards the objectives that a manufacturing company should achieve in order to be competitive and successful. But very few empirical researches have been carried out that both considers an objective that plays a critical role in the success of a manufacturing company and also provides a detailed process, methodology or framework to achieve that objective. Thus the literature on manufacturing strategy is well represented in the content side that depicts what to do to achieve success in manufacturing but is short in the process side which shows how to achieve the defined objectives. This research considered technology selection as an integral part of the manufacturing strategy and provided a practical approach to selecting manufacturing technology in the shape of a technology selection framework. Therefore it not only directed that technology selection is an important issue for the success of a manufacturing organisation but also provided a practical approach that was applied in the industry to test and verify its applicability. The feedback from the technology managers in the aerospace manufacturer indicated that there was a need for a systematic and analytical tool for technology selection as most of the decisions regarding manufacturing technology selection were implicit and unformalised and required explicit documented procedure for technology selection that could be beneficial to all especially the junior technology managers.

7.3.2.3 Supply Chain Integration

The literature on supply chains seems to be following the footsteps of the manufacturing strategy literature. Like the manufacturing literature the supply chain literature is also asking companies to identify their strategic objectives and advocating the achievement of these objectives. But again, as in the case of manufacturing, there is very little evidence available in the research that shows how to achieve those highlighted strategic objectives. One of the most favourite topics in supply chain literature is the collaboration among supply members and supply chain integration. Article after article can be found emphasising the need for collaboration and supply chain integration in this era of extended global supply chains. The term supply chain integration which has been used very loosely in the literature requires participation from all supply members. The first step in this participation is the willingness of an organisation to think beyond its boundaries and incorporate the business objectives and performance measures into its decision making process that are not only crucial to their own organisational success but are also critical to the success of the supply chain of which they are a constituent member. Therefore the technology selection framework presented in this research is an effort towards helping an organisation to think beyond its four walls while making key strategic decisions.

7.4 Wider Application of Research

The research carried out at the aerospace manufacturer to determine the manufacturing technology alternative considering the supply chain perspective can be adopted in any company or industry where technology selection is a major decision making area and where there is an increasing role played by the modern global supply chains. The research can easily be replicated in the automobile industry that deals with manufacturing technologies and extended supply chains. Similarly the selection of manufacturing technologies in the fast moving consumer goods industry (FMCG) dealing with global supply chains can be achieved using the technology selection framework. The framework can also be applied in the selection of non manufacturing technologies as it provides general guidelines for selection of technologies and manufacturing can be replaced by any other sort of technology for example information technology. In the case of information technology the most relevant application of the developed framework can be for the radio frequency identification systems (RFID) as they tend to provide a greater visualisation in a supply chain resulting in effective collaboration among the supply chain members. In future supply chains the selection of RFID technologies will be crucial to the success of an organisation so there exist huge potential for tools, techniques or methodologies that can facilitate an organisation in strategically selecting its RFID technology.

7.5 Research Limitations

The research was dependent on the participants for their knowledge regarding their technologies and required the technology managers to identify the opportunities and threats associated with their technology alternatives. The managers were well versed in identifying the opportunities associated with their technologies but were not as comfortable in identifying the threats associated with the technologies. This might be because of the reason that at first no one wanted to highlight any weak point of their technology: but eventually in the group meeting for identification of opportunities and threats the managers were able to highlight the opportunities and threats associated with all the technology alternatives. However they failed to identify the probability of occurrence of threat separately for different technologies considering different engine components in the manufacturing, supply chain and general environment. The reason for their failure can be that they were not familiar with this type of method of determining probability of occurrence of threat for each technology alternative considering each engine component in question. Moreover they were not able to attribute different values for each technology alternative for supply chain and general environment while considering the opportunities. This uniformity of numbers was explained as a lack of awareness regarding supply chain issues by the technology managers. If the technology managers were able to attribute different values for the threats in the three environments and different values for supply chain and general environments while considering opportunities the results presented in Chapter 6 could have been different. Despite these limitations the results presented in Chapter 6 were discussed with the technology managers and they were satisfied with the approach applied and results obtained (Appendix E) for the determination of strategic technology alternative and accepted the limitations as a learning lesson to explore more about threats associated with their technologies and the supply chain issues regarding the technology selection process.

The research was not developed with a capability to engage managers who were physically at a distance. The manufacturing and supply chain managers contributed towards this research and both of these functional managers were not able to participate in this research at the same time. The researcher acted as a facilitator between the two sides and carried out the requisite steps to implement the technology selection process. The participation of managers from both sides at the same time would have generated an interesting debate and have provided a rich insight into their group dynamics.

The research talked about supply chain perspectives in the manufacturing technology selection but does not include members of the supply chain in the technology selection process. The involvement of supply chain members in organisational decision making process proved a very challenging and time consuming task. Considering the time constraint and lack of familiarity of the organisation of any such kind of activity it was decided to focus the technology selection keeping in view the supply chain from a single organisation's point of view. It was the first step towards integration of the supply chain by considering how willing an organisation was to make its strategic decisions according to its supply chain requirements.

7.6 Future Research

The research presented in this thesis can be improved and facilitated by actively researching in the subject areas indicated.

7.6.1 Development of a Prototype Tool

The systematic evaluation of the technology selection framework in different industrial sectors as mentioned in section 7.4 should be a subject of future research. The validation of the technology selection framework in the industry can lead to a prototype tool development for technology selection process. The development of a software tool could greatly reduce the data needed to implement the technology selection framework. The tool should be developed with an idea of providing the necessary information that is mandatory for the decision maker for making the relevant strategic decisions. The availability of requisite information at a single source will able the time required to gather the necessary information for decision making to be reduced and will also be helpful in distributing standard unambiguous information to the decision makers throughout the organisation. Furthermore the prototype tool can be a step towards the commercialisation of the technology selection framework.

7.6.2 Improvement in Risk Calculation Techniques

The inclusion of risk calculations in the technology selection process is relatively new. The risk calculation methods used in the technology selection framework needs to be further investigated. The risk calculation techniques available in the literature need to be translated into industrial terms so that the technology managers can relate to these techniques and can provide an input that shows their real time risk concerns associated with different technology alternatives.

7.6.3 Group Decision Support System (GDSS) Facilitation

The technology selection framework presented in this research depends on the active participation of the managers involved in the decision making process. In the absence of facilities for group decision making (GDSS) it was complex to move back and forth between the two function of manufacturing and supply chain. Moreover as the researcher was acting as the messenger between the two sides there was a possibility of misinterpreting information. The collective participation of managers from two function would have further enhanced the decision making process. Therefore it needs to be investigated how the availability of GDSS can further crystallise the technology selection decision making. This research could benefit greatly from the developments in GDSS by making use of a remote decision making facility. A remote decision making facility can be used to incorporate the supply chain members in the decision making process and this can lead towards the real integration of the supply chain where supply chain affairs are duly addressed by supply chain members in the strategic technology selection process.

7.7 Conclusion

Notwithstanding shifts in employment towards service sectors the manufacturing sector remains a chief contributor to most countries GDP, whatever their stage of industrial development. Continued developments in manufacturing processes remain at the forefront of enabling successful supply chain performance in an increasingly competitive global environment. The choice of appropriate technologies at each stage of the supply chain, and the consequent selection of supply chain partnerships, is essential to achieving corporate marketing strategies. This research recognised supply chains as an essential emerging reality of the modern global business environment. The success of a business depends on the collaboration between different members of a supply chain. Collaborative effort within a supply chain can succeed by understanding the requirements of not only a single unit but by also considering the supply network while making strategic decisions. Therefore every single member of a supply chain when making strategic organisational decisions can play an important role in optimising the supply chain by considering the state of its constituent supply members. The technology selection framework presented in this thesis provides a mechanism for a company to integrate its supply chain by considering the benefits and concerns of their supply chain in the technology selection decision making process. The benefits and concerns of an organisation and the supply chain are addressed by evaluating the available technology alternatives in the shape of opportunities and threats associated with them in the manufacturing and supply chain environments. The evaluation of the technology alternatives considering the general environment factors facilitated the company to adhere to the consistently changing global and regional health and safety regulations and helped in selecting a manufacturing technology that could benefit from the existing government regulations. The inclusion of a broad range of factors under the umbrella of general environment provides completeness to the technology evaluation process. In short the main message of the technology selection framework presented in this research is the need for tools, techniques and methodologies to synchronise the supply chain and manufacturing within an organisation before taking on the bigger challenge of the integration of the entire supply network.

References

Abernathy, W.J. and Clark, K.B. (1985) "Innovative Mapping the Winds of Creative Destruction", *Research Policy,* Vol. 14, pp. 3-22.

Acur, N., Gertsen, F., Sun, H. and Frick, J. (2003) "The Formalisation of Manufacturing Strategy and its Influence on the Relationship between Competitive Objectives, Improvement Goals and Action Plans", *International Journal of Operations and Production Management,* Vol. 23, No. 10, pp. 1114-1141.

Adam, E.E. and Swamidas, P.M. (1989) "Assessing Operations Management from a Strategic Perspective", *Journal of Management,* Vol. 15, No. 2, pp. 181-203.

Anderson, J.G., Cleveland, G. and Schroeder, R.G. (1989) "Operations Strategy: A Literature Review", *Journal of Operations Management,* Vol. 8, No.2, pp. 133-158.

Anderson, J.G., Cleveland, G. and Schroeder, R.G. (1991) "The Process of Manufacturing Strategy: Some Empirical Observations and Conclusions", *International Journal of Operations and Production Management,* Vol. 11, No.3, pp. 86-110.

Anderson, M.G. and Katz, P.B. (1998) "Strategic Sourcing", *International Journal of Logistics Management,* Vol. No. 9, No. 1, pp. 1-13.

Barclays, I., Dann, Z., and Holroyd, P. (2000) "*New Product Development*", Oxford: Butterworth Heinemann.

Benbasat, I., Goldstein, D.K. and Mead, M. (1987) "The Case Research Strategy in Study of Information Systems", *MIS Quarterly,* Vol. 11, No. 3, pp. 369-386.

Bennett, D., Vaidya, K., Hongyu, Z. and Ming, W.Z. (1997) "Globalised Manufacturing and Technology Transfer Strategies", *IAMOT 97,* Gothenburg, Sweden, pp. 63-74.

Betz, F. (1998) "*Managing Technological Innovation*", USA: John Wiley & Sons.

Boyer, K.K. and Lewis, M.V. (2002) "Competitive Priorities: Investigating need for Trade Off in Operations Strategy", *Production and Operations Management,* Vol. 18, No. 4, pp. 356-373.

Bradley, P., Thomas, J., Gooley, T. and Cooke, J.A. (1999) "Future Competition: Supply Chain vs. Supply Chain", *Logistics Management and Distribution Report,* Vol. 38, pp. 20-21.

Brown, P.A. and Gibson, D.F. (1972) "A Quantified Model for Facility Site Selection Application to Multi-Plant Location Problem", *AIIE Transactions,* Vol. 4, pp. 1-10.

Burbidge, J.L. (1984) "*A Classification of Production System Variables*", in Hubner, H. (Ed) IFIP Production Management Systems: Strategies and Tools for Design, North Holland: Elsevier Science Publishers B.V.

Burgess, R. (1998) "Avoiding Supply Chain Management Failure : Lessons from Business Process Re-engineering", *International Journal of Logistics Management,* Vol. 9, No. 1,pp.15-23.

Cagliano, R., Caniato, F. and Spina, G. (2006) "The Linkage between Supply Chain Integration and Manufacturing Improvement Programmes", *International Journal of Operations and Production Management,* Vol. 26, No. 3, pp. 282-299.

Chatterji, D. (1996) "Accessing External Sources of Technology", *Research –Technology Management,* pp. 48-56.

Christy, D.P. and Grout, J.R. (1994) "Safeguarding Supply Chain Relationships", *International Journal of Production Economics,* Vol. 36, pp. 233-242.

Coghlan, D. and Brannick, T. (2001) "*Doing Action Research in Your Organization*", London: Sage

Cohen, M.A. and Lee, H.L. (1988) "Strategic Analysis of Integrated Production Distribution Systems: Models and Methods", *Operations Research,* Vol. 36, No. 2, pp. 216-228.

Cohen, M.A. and Moon, S. (1990) "Impact of Production Scale Economics, Manufacturing Complexity and Transportation Costs on Supply Chain Facility Networks", *Journal of Manufacturing and Operations Management,* Vol. 3, pp. 269-292.

Cook, R.L. and Rogowski, R.A. (1996) "Applying JIT Principles to Continuous Process Manufacturing Supply Chains", *Production and Inventory Management Journal,* First Quarter, pp. 12-17.

Cooper, A.C., Schendel, D. (1988) "*Strategic Response to Technological Threats*", in Tushman, M.L. and Moore, W.L. (Ed.) Readings in the Management of Innovation, Cambridge, MA: Ballinger, Second Edition.

Cooper, M.C., Ellram, L.M, Gardner, J.T. and Hanks, A.M. (1997) "Meshing Multiple Alliances", *Journal of Business Logistics,* Vol. 18, No. 1, pp. 67-89.

Corbett, C. and Van Wassenhove, L. (1993) "Trade-offs? What trade-offs? Competence and Competitiveness in Manufacturing Strategy", *California Management Review,* Vol. 35, No. 4, pp. 107-122.

Coughlan, P. and Coghlan, D. (2002) "Action Research for Operations Management", *International Journal of Operations and Production Management,* Vol. 22, No. 2, pp. 220-240.

Cox, A. (1999) "Power Value and Supply Chain Management", *Supply Chain Mangement: An International Journal,* Vol. 4, No. 4, pp. 167-175.

Dangayach, G.S. and Deshmukh, S.G. (2001) "Manufacturing Strategy Experience from Indian Manufacturing Companies", *Production Planning and Control,* Vol. 12, No. 8, pp. 775-786.

Das, S.R., Zahra, S.A., and Warkentin, M.S. (1991) "Integrating the Content and Process of Strategic MIS Planning", *Decision Sciences,* Vol. 22, No. 5, pp. 953-84.

Davis, T. (1993) "Effective Supply Chain Management", *Sloan Management Review,* pp. 35-46.

DeMeyer, A. (1992) "*An Empirical Investigation of Manufacturing Strategies in European Industry*", in Voss, C.A. (Ed.) Manufacturing Process and Content, London: Chapman and Hall.

Denzin, N. (1970) "*Strategies of Multiple Triangulation*", in Denzin, N. (Ed.) The Research Act in Sociology: A Theoretical Introduction to Sociological Method, pp. 297-313. New York: McGraw-Hill

Diaz, A.E. (1986) "The Software Portfolio: Priority Assignment Tool Provide Basic for Resource Allocation", *Industrial Engineering,* pp. 58-65.

Dyer, J.H. (1996) "Specialised Supplier Networks as a Source of Competitive Advantage: Evidence from the Auto Industry", *Strategic Management Journal,* Vol. 17, pp. 649-666.

Dyer, J.H. and Singh, H. (1998) "The Relational View: Cooperative Strategy and Source of Inter-organisational Competitive Advantage", *Academy of Management Review,* Vol. 23, No. 4, pp. 660-679.

Dyer, R.F. and Forman, E.H. (1992) "Group Decision Support with the Analytic Hierarchy Process", *Decision Support Systems,* Vol. 8, No. 2, pp. 99-124.

Easterby-Smith, M., Thorpe, R. and Lowe, A. (1997) "*Management Research: An Introduction*", London: Sage Publications.

Eden, C. and Huxham, C. (1996) "Action Research for Management Research", *British Journal of Management,* Vol. 7, pp. 75-86.

Endosomwan, J.A. (1989) "*Integrating Innovation and Technology Management*", USA: John Wiley and Sons, First Edition, pp. 1-27.

Fine, C.H. and Hax, A.C. (1985) "Manufacturing Strategy: A Methodology and an Illustration", *Interfaces,* Vol. 15, No. 6, pp. 28-46.

Fine, C.H. (1999) "Clock Speed Strategies for Supply Chain Advantage", *Supply Chain Management Review,* Global Supplement, pp. 4-7.

Fisher, M.L. (1997) "What is the Right Supply Chain Strategy for Your Product?" *Harvard Business Review,* Vol. 75, No. 2, March- April, pp. 105-116.

Flynn, B., Schroeder, R.G. and Flynn, E.J. (1999) "World Class Manufacturing: An Investigation of Hayes and Wheelwright's Foundation", *Journal of Operations Management,* Vol. 17, No. 3, pp. 249-269.

Flynn, B., Sakakibara, S., Schroeder, R.G., Bates, K.A. and Flynn, E.J. (1990) "Empirical Research Methods in Operations Management", *Journal of Operations Management,* Vol. 9, No. 2, pp. 250-284.

Frohlich, M. and Westbrook, R. (2001) "Arcs of Integration: An International Study of Supply Chain Strategies", *Journal of Operations Management,* Vol. 19, pp. 185-200.

Frohman, A.L. (1985) "Putting Technology into Strategic Planning", *California Management Review,* Vol. 27, No. 2, pp. 45-54.

Gagnon, R.J., Haldar, S. (1997) "Assessing Advanced Engineering Technologies", *International Journal of Technology Management,* Vol. 14, pp. 439-469.

Ghodsypour, S. and O'Brien, C. (1998) "A Decision Support System for Supplier Selection using an Integrated Analytical Hierarchy Process and Linear Programming", *International Journal of Production Economics,* Vol. 56-57, pp. 199-212.

Gouvea da Costa, S.E., Platts, K.W. and Fleury, A. (2006) "Strategic Selection of Advanced Manufacturing Technologies Based on the Manufacturing Vision", *International Journal of Computer Applications in Technology,* Vol. 27, No. 1, pp. 12-23.

Gresswell, T., Childe, S. and Maull, R. (1998) "*Three Manufacturing Strategy Arch types- A Framework for the Aerospace Industry*", in Bititci, U. and Carrie, A. (Ed) Strategic Management of the Manufacturing Value Chain, Dordechet: Kluwer, pp. 53-61.

Gummesson, E. (2000) "*Qualitative Methods in Management Research*", Thousand Oaks, CA: Sage.

Gunasekaran, A., Patel, C. and McGaughey, R.E. (2004) "A framework for Supply Chain Performance Measurement", *International Journal of Production Economics,* Vol. 87, pp. 333-347.

Harland, C.M., Lamming, R.C. and Cousins, P.D. (1999) "Developing the Concept of Supply Strategy", *International Journal of Operations and Production Management,* Vol. 19, No. 7, pp. 650-673.

Hayes, R.H. and Wheelwright, S.C. (1984) "*Restoring Our Competitive Edge: Competing Through Manufacturing*", New York: John Wiley and Sons.

Hayes, R.H. and Wheelwright, S.C. (1988) "*Dynamic Manufacturing*", New York: The Free Press

Hayes, R.H. and Pisano, P.G. (1994) "Beyond World- Class: The New Manufacturing Strategy", *Harvard Business Review,* pp. 77-86.

Hayes, R.H. and Upton, M.D. (1998) "Operations Based Strategy", *California Management Review,* Vol. 40, No. 4, pp. 8-25.

Hill, T.J. (1985) "*Manufacturing Strategy: The Strategic Management of the Manufacturing Function*", Basingstoke: Macmillan.

Hill, T.J. (1989) "*Manufacturing Strategy: Text and Cases*", Homewood, IL: Irwin.

Hill, T.J. (1993) *"Manufacturing Strategy, The Strategic Management of the Manufacturing Function "*, London: Macmillan, Second Edition.

Hill, T.J. (1995) "*Manufacturing Strategy: Text and Cases*", Basingstoke: Macmillan.

Hussey, J. and Hussey, R. (1997) "*Business Research: A Practical Guide for Undergraduate and Postgraduate Students*", London: Macmillan Press.

Jack, E.P. and Raturi, A.S. (2006) "Lessons Learned from Methodical Triangulation in Management Research", *Management Research News*, Vol. 29, No. 6, pp. 345-357.

Jaikumar, R. (1986) "Post Industrial Manufacturing", *Harvard Business Review,* Vol. 64, pp. 123-129.

Johnson, S.C., Marsh, G. and Tyndall, G. (1998) "The Path to Higher Share Holder Value", *Chief Executive,* Vol. 136, July- August, pp. 38-41.

Kengpol, A. and O'Brien, C. (2001) "The Development of a Decision Tool for the Selection of Advanced Technology to Achieve Rapid Product Development", *International Journal of Production Economics,* Vol. 69, pp. 177-191.

Khouja, M. (1995) "The Use of Data Envelopment Analysis for Technology Selection", Computers *and Industrial Engineering,* Vol. 28, No. 1, pp. 123-132.

Kim, Y. and Lee, J. (1993) "Manufacturing Strategy and Production Systems: An Integrated Framework", *Journal of Operations Management,* Vol. 11, pp. 3-15.

Kleindorfer, P.R. and Partovi, F.Y. (1990) "Integrating Manufacturing Strategy and Technology Choice", *European Journal of Operational Research,* Vol. 47, pp. 214-224.

Lederer, A.L. and Sethi, V. (1998) "Seven Guidelines for Strategic Information Systems Planning", *Information Strategy: The Executives Journal,* Vol. 15, No. 1, pp. 23-28.

Lee, H.L. and Feitzinger, E. (1995) "Product Configuration and Postponement for Supply Chain Efficiency", *Institute of Industrial Engineers,* Fourth Industrial Engineering Research Conference Proceedings, pp. 43-48.

Leong, G.K., Snyder, D.L., Ward, P.T. (1990) "Research in the Process and Content of Manufacturing Strategy", *Omega,* Vol. 18, No. 2, pp. 109-122.

Lockamy, A. (2004) "Linking Manufacturing and Supply Chain Strategies: A conceptual Framework", *International Journal of Manufacturing Technology and Management,* Vol. 6, No. 5, pp. 401-425.

Lowe, A., Ridgway, K. and Atkinson, H. (2000) "QFD in New Production Technology Evaluation", *International Journal of Production Economics,* Vol. 67, pp. 103-112.

Lummus, R.R., Vokurka, R.J. and Alber, K.L. (1998) "Strategic Supply Chain Planning", *Production and Inventory Management Journal,* Vol. 39, No. 3, pp. 49-58.

Lynch, R. (1997) "*Corporate Strategy*", London: Pitman.

Mangan, J., Lalwani, C. and Gardner, B. (2004) "Combining Quantitative and Qualitative Methodologies in Logistics Research", *International Journal of Physical Distribution and Logistics Management,* Vol. 34, No. 7, pp. 565-578

Mapes, J., New, C. and Szwejczewski, M. (1997) "Performance Trade-offs in Manufacturing Plants", *International Journal of Operations and Production Management,* Vol. 17, No. 10, pp. 1020-1033.

Marucheck, A., Pannesi, R. and Anderson, C. (1990) "An Exploratory Study of the Manufacturing Strategy Process in Practice", *Journal of Operations Management,* Vol. 9, No. 1, pp. 101-123.

Maskell, B.H. (1991) "*Performance Measurement for World Class Manufacturing*", Oregon: Productivity Press Portland.

Menda, D. and Dilts, D. (1997) "The Manufacturing Strategy Formulation Process: Linking Multifunctional View Points", *Journal of Operations Management,* Vol. 15, pp. 223-241.

Miller, J.G., Hayslip, W. (1989) "Implementing Manufacturing Strategic Planning", *Planning Review,* July-August.

Miller, J.G. and Roth, A.V. (1994) "A Taxonomy of Manufacturing Strategies", *Management Science,* Vol. 40, No. 3, pp. 285-304.

Minor, E.D, Hensley, R.L. and Wood (1994) "A Review of Empirical Manufacturing Strategy Studies", *International Journal of Operations and Production Management,* Vol. 14, No. 1, pp. 5-25.

Mohanty, R.P. and Deshmukh, S.G. (1998) "Advanced Manufacturing Technology Selection: A Strategic Model for Learning and Evaluation", *International Journal of Production Economics,* Vol. 55, pp. 295-307.

Morone, J. (1989) "Strategic Use of Technology", *California Management Review,* Vol. 31, No. 4, pp. 91-110.

Naslund, D. (2002) "Logistics Needs Qualitative Research: Especially Action Research", *International Journal of Physical Distribution and Logistics Management,* Vol. 32, No. 5, pp. 321-38.

Next-Generation Manufacturing (NGM) Project (1997) "*Next-Generation Manufacturing: A Framework for Action*", Agility Forum: Leaders for Manufacturing, and Technologies Enabling Agile Manufacturing. Bethlehem, PA.

Pagh, J.D. and Cooper, M.C. (1998) "Supply Chain Postponement and Speculation Strategies: How to Choose the Right Strategy", *Journal of Business Logistics,* Vol. 19, No. 2, pp. 13-33.

Pine, B.J., Victor, B. and Boynton, A.C. (1993) "Making Mass Customisation Work", *Harvard Business Review,* September-October, pp. 108-119.

Piippo, P. and Tuominen, M. (1990) "*Promoting Innovation Management by Decision Support Systems: Facilitating New Products Relevance to the Corporate Objectives*", in Jurgen Alleesch (Ed) Consulting in Innovation Practice-Method- Perspectives, North Holland: Elsevier Science Publishers, pp. 267-292.

Platts, K.W. and Gregory, M.J. (1990) "Manufacturing Audit in The Process of Strategy Formulation", *International Journal of Operations and Production Management,* Vol. 10, No. 9, pp. 5-26.

Platts, K.W. and Gregory, M.J. (1992) "*Manufacturing Audit in The Process of Strategy Formulation*", in Voss, C.A (Ed.) Manufacturing Strategy Process and Content, London: Chapman and Hall.

Platts, K.W. (1994) "Characteristics of Methodologies for Manufacturing Strategy Formulation", *Computer Integrated Manufacturing Systems,* Vol. 7, No. 2, pp. 93-99.

Platts, K.W., Mills, J.F., Bourne, M.C., Neely, A.D., Richard, A.H. and Gregory, M.J. (1996) "Evaluating Manufacturing Strategy Formulation Strategy Processes", *International Journal of Production Economics,* Vol. 46-47, pp. 233-240.

Poirier, C.C. (1999) "*Advanced Supply Chain Management: How to Build a Sustained Competitive Advantage*", San Francisco: Berrett-Koehler Publishers.

Porter, M.E. (1980) "*Competitive Strategy*", New York: Free Press.

Porter, M.E. (1983) "*The Technical Dimension of Competitive Strategy*", in Rosenbloom, R.S. (Ed.) Research on Technological Innovation, Management and Policy, Greenwich, CT: JAI Press.

Porter, M.E. (1985) "*Competitive Advantage*", New York: Free Press.

Porter, M.E. (1996) "What is Strategy?" *Harvard Business Review,* November-December, pp. 61-78.

Prahalad, C.K. and Hamel, G. (1990) "The Core Competence of the Organisation", *Harvard Business Review,* May –June 1990, pp. 79-91.

Punniyamoorthy, M. and Ragavan, P.V. (2003) "A Strategic Decision Model for the Justification of Technology Selection", *International Journal of Advanced Manufacturing Technology,* Vol. 21, pp. 72-78.

Rice, J.B. and Hoppe, R.M. (2001) "Supply Chain versus the Supply Chain: The Hype and the Reality", *Supply Chain Management Review,* September-October.

Richardson, P.R., Taylor, A.J. and Gordon, J. (1985) "A Strategic Approach to Evaluating Manufacturing Performance", *Interfaces*, Vol. 15, No. 6, pp. 15-27.

Robinson, E.P. Jr. and Satterfield, R.K. (1998) "Designing Distribution Systems to Support Vendor Strategies in Supply Chain Management", *Decision Sciences,* Vol. 29, No. 3, pp. 685-706.

Robson, C. (2002) "*Real World Research*". U.K: Blackwell Publishers.

Rosenzweig, E.D., Roth, A.V. and Dean, J.W. (2003) "The Influence of an Integration Strategy on Competitive Capabilities and Business Performance: An Exploratory Study of Consumer Products Manufacturers", *Journal of Operations Management,* Vol. 21, pp. 437-456.

Saaty, T.L. (1980) "*The Analytic Hierarchy Process*", New York: McGraw-Hill.

Saaty, T.L. (1982) "*Decision Making for Leaders*", Belmont, CA: Lifetime Learning Publications.

Schein, E.H. (1987) "*The Clinical Perspective in Fieldwork*", Thousand Oaks, CA: Sage.

Schonberger, R.J. (1986) "*World Class Manufacturing: The Lessons of Simplicity Applied*", New York: The Free Press.

Schroeder, R.G., Anderson, J.G. and Cleveland, G, (1986) "The Content of Manufacturing Strategy: An Empirical Study", *Journal of Operations Management,* Vol. 6, No. 4, pp. 405-415.

Shehabuddeen, N., Probert, D. and Phaal, R. (2006) "From Theory to Practice: Challenges in Operationalising a Technology Selection Framework", *Technovation,* Vol. 26, pp. 324-335.

Skrabec, Q.R. Jr. (1999) "Cooperative Advantage: A New Measure of Performance", *National Productivity Review,* Spring, pp. 69-73.

Skinner, W. (1969) "Manufacturing-The Missing Link in Corporate Strategy", *Harvard Business Review,* May-June, pp. 136-145.

Skinner, W. (1974) "The Focused Factory", *Harvard Business Review,* Vol. 52, No.3, May –June, pp. 113-121.

Skinner, W. (1978) "*Manufacturing in the Corporate Strategy*", New York: John Wiley

Skinner, W. (1985) "*Manufacturing the Formidable Competitive Weapon*", New York: Wiley.

Slack, N. (1983) "Flexibility as a Manufacturing Objective", *International Journal of Operations and Production Management,* Vol. 3, No. 3, pp. 4-13.

Slack, N. (1994) "The Importance Performance Matrix as a Determinant of Improvement Priority", *International Journal of Operations and Production Management,* Vol. 14, No. 5, pp. 59-75.

Slack, N., Chambers, S., Harland, C., Harrison, A. and Johnston, R. (1995) "*Operations Management*", London: Pitman Publishing.

Slack, N., Chambers, S. and Johnston, R. (2001) "*Operations Management*", Harlow: Pearson Education Limited.

Steele, L.W. (1989) "*Managing Technology – The Strategic View*", New York: McGraw-Hill Book.

Stillman, H.M. (1997) "How ABB Decides on the Right Technology Investments", *Research –Technology Management,* November-December, pp. 14-22.

Stobaugh, R. and Telesio, P. (1983) "Match Manufacturing Strategies and Product Policies", *Harvard Business Review,* March –April.

Susman, G. and Evered, R. (1978) "An Assessment of the Scientific Knowledge of Action Research", *Administrative Science Quarterly,* Vol. 23, pp. 582-603

Swindle, R. (1985) "Financial Justification of Capital Projects", *Proceedings of the Autofact 85 Conference,* Detroit, MI.

Swink, M. and Way, H.M. (1995) "Manufacturing Strategy Propositions, Current Research, Renewed Directions", *International Journal of Operations and Production Management,* Vol. 15, No. 7, pp. 4-26.

Swink, M., Narasimhan, R. and Wang, C. (2007) "Managing Beyond the Factory Walls: Effects of Four Types of Strategic Integration on Manufacturing Plant Performance", *Journal of Operations Management,* Vol. 25, pp. 148-164.

Tavana, M. and Banerjee, S. (1995) "Strategic Assessment Model (SAM) - A Multiple Criteria Decision-Support System for Evaluation of Strategic Alternatives", *Decision Sciences,* Vol. 26, No. 1, pp. 119-143.

Tavana, M. (2003) "CROSS: A Multi-Criteria Group Decision Making Model for Evaluating and Prioritising Advanced Technology Projects at NASA", *Interfaces,* Vol. 33, No. 3, pp. 40-56.

Tingling, P. and Parent, M. (2004) "An Exploration of Enterprise Technology Selection and Evaluation", *Journal of Strategic Information Systems,* Vol. 13, pp. 329-354.

Torkkeli, M. and Tuominen, M. (2001) "Use of GDSS in Technology Selection: Experiences and Findings", *Proceedings of the 34th Hawaii International Conference on System Sciences-2001.*

Torkkeli, M. and Tuominen, M. (2002) "The Contribution of Technology Selection to Core Competencies", *International Journal of Production Economics,* Vol. 77, pp. 271-284.

Tipping, J.W., Zeffren, E. and Fusfeld, A.R. (1995) "Assessing the Value of Your Technology", *Research- Technology Management,* pp. 22-39.

Tunalv, C. (1990) "Manufacturing Strategies and De-centralisation", *International Journal of Operations and Production Management,* Vol. 10, No. 2, pp. 107-19.

Twiss, B. (1995) "*Managing Technological Innovation*", Glasgow: Pitman Publishing. Fourth Edition, pp. 123-160.

Tyndall, G., Gopal, C., Partsch, W. and Kamauff, J. (1998) "*Supercharging Supply Chains: New Ways to Increase Value Through Global Operational Excellence*", New York: John Wiley and Sons.

Vargas, L.G. (1990) "An Overview of Analytic Hierarchy Process and its Applications", *European Journal of Operational Research,* Vol. 48, pp. 2-8.

Voss C.A. (1986) "Managing Advanced Manufacturing Technology", *International Journal of Operations and Production Management,* Vol. 6, No. 3, pp. 4-7.

Voss C.A. (1995) "Alternative Paradigms of Manufacturing Strategy", *International Journal of Operations and Production Management,* Vol. 15, No. 4, pp. 5-16.

Westbrook, R. (1995) "Action Research a New Paradigm for Research in Production and Operations Management", *International Journal of Operations and Production Management,* Vol. 15, No. 12, pp. 6-20.

Wittgenstein, L. (1961) "*Tractatus Logico-Philosophicus*", London: RKP.

Woodward, J. (1965) "*Industrial Organisation, Theory and Practice*", London: Oxford University Press.

Yap, C.M. and Souder, W.E. (1993) "A Filter System for Technology Evaluation and Selection", *Technovation,* Vol. 13, No. 7, pp. 449-469.

APPENDIX A

Company Introductory Interview

Objectives

1. To find out about the manufacturing business.
2. To find out specific issues regarding Technology Selection
3. To find out about the supply chain activities

Questions

1. The environment and nature of the business

    - Nature of business
    - Product –mix
    - Manufacturing characteristics
    - Technology status
    - Supply Chain Collaboration

2. What is the structure of your global and regional manufacturing supply chain?

3. How do you manage these supply chains?

4. What is your position in the supply chain?

5. What kinds of technologies are involved in your current business operations?

6. Does manufacturing technology play a significant role in the success of your business?
7. How do you select manufacturing technology?

8. What factors are important in making technology selection decisions?

9. What kind of models can be helpful in selecting manufacturing technology?

10. Is it important to synchronise the technology along the supply chain to optimise the supply chain?

11. What steps should be involved in selecting a manufacturing technology selection framework from a supply chain perspective?

12. What support will you provide in developing a framework for manufacturing technology selection?

Appendix B

Interview for Development of Technology Selection Framework

Product Profile: ____________________

1. How important is the selection of the right kind of manufacturing technology for this product?

   a. Very Important ☐ b. Important ☐ c. Indifferent ☐ d. Less Important ☐
   e. Not Important ☐

2. Is your manufacturing technology selection influenced by the technology state of your supplier/distributor in your supply chain?

   a. Yes ☐ b. No ☐ c. Other ________________

3. How important is it for you to select your manufacturing technology keeping in view the technology status of your supplier/distributor (supply chain)?

   a. Very Important ☐ b. Important ☐ c. Indifferent ☐ d. Less Important ☐
   e. Not Important ☐

4. How important is it to evaluate the current supply chain performance of the product (based on supply chain performance measures like cost, quality, lead time etc) compared to its market competitors before selecting a particular manufacturing technology?

   a. Very Important ☐ b. Important ☐ c. Indifferent ☐ d. Less Important ☐
   e. Not Important ☐

5. Evaluation of current supply chain performance for the purpose of manufacturing technology selection requires?

   a. Selection of Participants ☐
   b. Understanding of the purpose of the process ☐
   c. Understanding of business objective of the company ☐
   d. Other ____________________________________

6. Evaluation of current supply chain performance for the purpose of manufacturing technology selection provides?

   a. Identification of strengths & weaknesses ☐
   b. Relative comparisons with market competitors ☐
   c. Re-evaluation of business strategy ☐
   d. Other ______________________

7. How important is it to determine the critical supply chain performance factors/ market competition factors (like cost, quality, lead time etc) of a business before selecting a particular manufacturing technology perspective?

   a. Very Important ☐ b. Important ☐ c. Indifferent ☐ d. Less Important ☐
   e. Not Important ☐

8. Determination of critical supply chain factors/market competition factors for the selection of manufacturing technology requires?

   a. Definition of important factors for market competition ☐
   b. Evaluation of supply chain members (their business priorities) ☐
   c. Collaboration with supply chain members (working towards same business objective) ☐
   d. Other ______________________

9. Determination of critical supply chain/market competition factors for the selection of manufacturing technology provides?

   a. Identification of core competency ☐
   b. Set of factors for market competition ☐
   c. Re-defined Business Strategy ☐
   d. Other ______________________

10. How important is it to establish a time horizon /planning range (short time, medium time, long time) to necessitate the implementation of supply chain/market competition factors while considering selection of a manufacturing technology?

    a. Very Important ☐ b. Important ☐ c. Indifferent ☐ d. Less Important ☐
    e. Not Important ☐

11. Determination of time horizon for implementation of supply chain/market competition factors requires?

    a. Nature of market/business ☐
    b. Support from the supply network ☐
    c. Other ________________

12. Determination of time horizon for implementation of supply chain/market competition factors provides?

    a. Future vision of the business (supply chain) ☐
    b. Requirement of means to execute the planned action ☐
    c. Defining resource allocation ☐
    d. Other ________________

13. How important is to identify the potential manufacturing technologies to fulfil the criteria of supply chain/market competition factors (like cost, quality, lead time, etc) within a specific time horizon before selection of a particular technology?

    a. Very Important ☐ b. Important ☐ c. Indifferent ☐ d. Less Important ☐
    e. Not Important ☐

14. Identification of a particular manufacturing technology to fulfil the criteria of supply chain/market competition requires?

    a. Time Horizon ☐
    b. Critical Supply Chain Factors ☐
    c. Technology status of supply chain members ☐
    d. Other ________________

15. Identification of a particular manufacturing technology to fulfil the criteria of supply chain/market competition provides?

    a. Identification of latest and advanced technologies ☐
    b. List of possible technologies to achieve the goal ☐
    c. Detailed characteristics of each alternative ☐
    d. Other ________________

16. How important is the detailed assessment of identified manufacturing technologies in order to select the right manufacturing technology?

    a. Very Important ☐ b. Important ☐ c. Indifferent ☐ d. Less Important ☐
    e. Not Important ☐

17. Detailed assessment of manufacturing technologies for the purpose of technology selection requires?

    a. Expert analysis ☐
    b. Technology associated Opportunities ☐
    c. Technology associated Threats ☐
    d. Other ______________________________

18. Detailed assessment of manufacturing technologies for the purpose of technology selection provides?

    a. Detailed analysis under different scenarios ☐
    b. Defined set of technology to achieve the goal ☐
    c. 'What If' analysis in case business objective changes ☐
    d. Other ______________________________

19. How important is the assessment of risk associated with a technology alternative while selecting a manufacturing technology?

    a. Very Important ☐ b. Important ☐ c. Indifferent ☐ d. Less Important ☐
    e. Not Important ☐

Appendix C

Supply Chain Evaluation Questionnaire

Product Profile: ____________________

1. Please identify the supply chain performance objectives that are important to the success of the product?

a. Cost ☐ b. Quality ☐ c. Lead Time ☐ d. New Product Development ☐
e. Flexibility ☐ f. Other ____________________

2. For each of the above mentioned objectives please identify how important is this objective to your product supply chain?

	Very Important	Important	Indifferent	Less Important	Not Important
Cost					
Quality					
Lead Time					
New Product Development					
Flexibility					
Others…..					

3. What is your supplier's performance (supply chain) at delivering the above objectives to for the given product?

	Excellent	Very Good	Good	Satisfactory	Unsatisfactory
Cost					
Quality					
Lead Time					
New Product Development					
Flexibility					
Others....					

4. For this product or service does each performance objective meet the following?

	Provide a crucial advantage with customers	Provide an important advantage with most customers	Provide a useful advantage with most customers	Need to be at least up to good industry standard	Need to be around median industry standard	Need to be within close range of the rest of the industry	Do not usually come into customers consideration but could become more important in future	Very rarely come into customers considerations	Never come into consideratio[n] by customer[s]
Cost									
Quality									
Lead Time									
New Product Development									
Flexibility									
Others…..									

5. In this market sector or for this product group how is your achieved performance in each of the performance objectives?

	Considerably better than nearest competitor	Clearly better than nearest competitor	Marginally better than nearest competitor	Marginally better than most competitors	Same as most competitors	Within striking distance of the main competitors	Marginally worse than most competitors	Worse than most competitors	Consistent worse than most competitor
Cost									
Quality									
Lead Time									
New Product Development									
Flexibility									
Others…..									

Appendix D

Technology Probability Table

Considering a typical identified engine component please identify the opportunities and threats presented by each technology alternative in manufacturing, supply chain and general environment and also highlight the probability of occurrence of the identified opportunity or threat if a particular technology is selected.

ınufacturing vironment portunity	**Laser Tech**	**EBW Tech**	**FSW Tech**	**Plasma Tech**	**SMD Tech**	**DLD Tech**	**LFW Tech**	**RFW Tech**	**Isostatic Tech**	**Certainty Equivalence C.E**
velopment Cost uction										
velopment time uction										
t cost reduction										
intenance cost										
ısumable cost										
ign bler/Design tibility										
sitivity to raw erials										
eased luctivity										
lity levels										
ormance ancement over above irement										
Potential										
ply Chain ironment ortunity										
ity to influence shape demand										
ity to Handle and flexibility										
ıine ctiveness										
itivity to raw rials										
time reduction										
ations/Lean ıfacturing										

ıeral ironment ɔortunity											
efits from Govt ulations											
ɜ of Conforming ı HSE Legislation											
ɜ of Technology ɜcasting											
ıufacturing ironment eat											
ital Cost											
f resistance to ıge											
ning Expenses											
em Integration											
ınology Maturity											
ntial new pment ıllation/relocation of disruption)											
Transfer/MCR ıufacturing ge request)											
ɔly Chain ironment ɜat											
lequate nology											
nical Ability											
wledge of ıess ɔrtunities											
mitment to vation											
ıcial Constraints											
nology Strategy											
ɜral ronment at											
Cycle Analysis											
n on Investment											
ge of Govt lations											
ıology rtainty											

Appendix E

Process Evaluation Questionnaire

Please indicate the most appropriate number from 1-5 on each statement corresponding most closely to your desired response on question number 1 to 8. Question 9 and 10 are to capture general comments about the technology selection framework.

1. I found the framework useful.
   1- Not at all...5- Very much ...

2. I found the framework flexible.
   1- Not at all...5- Very much ...

3. I can understand the message given by the framework.
   1- Not at all...5- Very much ...

4. To what extent were you satisfied with instructions to use the framework?
   1- Not at all...5- Very much ...

5. The content of and instructions was sufficient for me to perform the tasks.
   1- Not at all...5- Very much ...

6. The framework was easy to comprehend and apply.
   1- Not at all...5- Very much ...

7. The linkage between different steps of framework was logical.
   1- Not at all...5- Very much ...

8. The final output of the framework was presented in a useful way.
   1- Not at all...5- Very much ...

9. In your opinion what are the strengths of this framework?

10. In your opinion what are the weaknesses of this approach?

Appendix F

Technology Ranking Familiarisation Questionnaire

Assuming a typical identified engine component kindly answer the following questions (for the assumed component) by tick marking the box. In case none of the available choices being applicable please provide comments.

1. Development cost with LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

2. Development time with LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

3. Unit cost with LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

4. Maintenance cost with LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

5. Consumable Cost associated with LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

6. Design enabling/design flexibility with LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

7. Sensitivity to raw materials with LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

8. Productivity with LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

9. Quality with LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

10. IPR potential of LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

11. Volume flexibility with LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

12. Machine effectiveness (meaning utilization of machine-operational hours for performing jobs) for LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ____________________

13. Lead time (total time for a job from start to finish) for LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ____________________

14. LFW technology enables Lean Manufacturing/Operations
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ____________________

15. LFW technology can benefit from Govt. regulations
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ____________________

16. Conformance with HSE legislation in case of LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ____________________

17. LFW technology future forecasting is
a. easier than EBW and easier than Laser ☐
b. easier than EBW and difficult than Laser ☐
c. difficult than EBW and easier than Laser ☐
d. easier than EBW easier than Laser ☐
e. Others ____________________

18. Capital cost involved with LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

19. Staff resistance/reservation for implementing LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

20. Training expenses related to LFW technology are
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

21. System integration with LFW technology is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

22. LFW technology maturity is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

23. Potential new equipment installation and relocation in case of LFW technology is
a. easier than EBW and easier than Laser ☐
b. easier than EBW and difficult than Laser ☐
c. difficult than EBW and easier than Laser ☐
d. difficult than EBW difficult than Laser ☐
e. Others ______________________________

24. Part transfer/manufacturing change request in case of LFW technology is
a. easier than EBW and easier than Laser ☐
b. easier than EBW and difficult than Laser ☐
c. difficult than EBW and easier than Laser ☐

d. difficult than EBW difficult than Laser ☐
e. Others ______________________________

25. In advanced technologies LFW is ranked
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

26. LFW technology requires technical ability
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

27. In the aerospace business LFW technology provides business opportunities
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

28. LFW technology can provide commitment to innovation
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

29. Financial constraints associated with LFW technology are
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

30. Life cycle of LFW technology is
a. longer than EBW and longer than Laser ☐
b. longer than EBW and shorter than Laser ☐
c. shorter than EBW and longer than Laser ☐
d. shorter than EBW shorter than Laser ☐
e. Others ______________________________

31. Return on investment with LFW technology over its life is
a. higher than EBW and higher than Laser ☐
b. higher than EBW and lower than Laser ☐
c. lower than EBW and higher than Laser ☐
d. lower than EBW lower than Laser ☐
e. Others ______________________________

Appendix G

Pilot Study

1. Strategic Assessment Model (SAM) Calculations

The following steps describe the chronological order in which the calculations are carried out in the Microsoft Excel for strategic technology alternative using SAM.

a. Opportunity Calculations:

Step 1 & Step 2: The first two steps involved calculations of constant (K)

$$K = 1/\ln q$$

Where

q = Total Number of Alternatives

Step 3: In step 3 entropy measure of all the defined opportunities in three defined decision making environments manufacturing, supply chain and general environment is determined

$$e(p_{uij}) = -K\sum_{m=1}^{q}\frac{p_{uij}^{m}}{P_{ij}}\ln\frac{p_{uij}^{m}}{P_{ij}}$$

Where

$e(p_{uij})$ = Entropy Measure of jth Opportunity Factor in the ith Environment

q = Total Number of Alternatives

$K = 1/\ln q$

p_{uij}^{m} = The mth Probability of Occurrence of the jth Opportunity Factor in the ith Environment

P_{ij} = Sum of Probability of Occurrences of the jth Opportunity Factor in the ith Environment

Step 4: In step 4 the Total Entropy is calculated.

$$E = \sum_{j=1}^{Nui} e(p_{uij})$$

Where

E = Total Entropy

N_{ui} = Number of Opportunity Factors in the ith Environment

$e(p_{uij})$ = Entropy Measure of the jth Opportunity Factor in the ith Environment

Step5: In step 5 intrinsic weight of all the opportunities in all three decision making environments is determined.

$$F_{uij} = \frac{1}{N_{ui} - E}[1 - e(p_{uij})] \text{ .... (2)}$$

Where

F_{uij} = Intrinsic Weight for the jth opportunity Factor in the ith Environment

N_{ui} = Number of Opportunity Factors in the ith Environment

E = Total Entropy

Step 6: In step 6 initial weight associated with each opportunity factor in all three decision making environment is determined using Analytical Hierarchy Process (AHP) and then overall importance weight of an opportunity is determined.

$$\hat{F}_{uij} = \frac{F_{uij}.w_{uij}}{\sum_{j=1}^{Nui} F_{uij}.w_{uij}}$$

Where

$\hat{F}_{uij}$ = Overall Importance Weight for the jth opportunity Factor in the ith Environment

F_{uij} = Intrinsic Weight for the jth opportunity Factor in the ith Environment

w_{uij} = Initial Weight Associated for the jth opportunity Factor in the ith Environment

Step 7: In step 7 risk aversion factors are calculated for each opportunity (detail in Appendix I)

Step8: In step 8 the risk adjusted opportunity value is calculated.

$$U^m = \sum_{i=1}^{3} W_{ui}[\sum_{j=1}^{Nui} \hat{F}_{uij}\{\frac{-1}{r_{uij}} \ln(1 - p^m_{uij} + p^m_{uij} e^{-r_{uij}})\}]$$

Where

U^m = Total Weighted Risk Adjusted Opportunity Value of the mth Alternative

W_{ui} = The ith Environment Weight for Opportunity

N_{ui} = Number of Opportunity Factors in ith Environment

$\hat{F}_{uij}$ = Overall Importance Weight for the jth Opportunity Factor in the ith Environment

r_{uij} = Risk Aversion Constant for jth Opportunity Factor in the ith Environment

p^m_{uij} = The mth Probability of Occurrence of jth Opportunity Factor in the ith Environment

b. Threat Calculations:

The procedure for determination of threat calculations is exactly the same like opportunity calculations using the similar equations only replacing opportunity factor values with the threat value factors. The final risk adjusted threat value is calculated using the following equation:

$$T^m = \sum_{t=1}^{3} W_{ti}[\sum_{j=1}^{Nti} \hat{F}_{tij}\{\frac{-1}{r_{tij}}\ln(1-p^m_{tij}+p^m_{tij}e^{r_{tij}})\}]$$

Where

T^m = Total Weighted Risk Adjusted Threat Value of the mth Alternative

W_{ti} = The ith Environment Weight for Threat

N_{ti} = Number of Threat Factors in the ith Environment

$\hat{F}_{tij}$ = Overall Importance Weight for the jth Threat Factor in the ith Environment

r_{tij} = Risk Aversion Constant for jth Threat Factor in the ith Environment

p^m_{tij} = The mth Probability of Occurrence of jth Threat Factor in the ith Environment

c. Overall Risk Adjusted Strategic Value:

The overall risk adjusted strategic value for technology alternative is calculated by using the following equation:

$$V^m = U^m + T^m$$

Where

V^m = Total Weighted Risk Adjusted Strategic Value of the mth Alternative

U^m = Total Weighted Risk Adjusted Opportunity Value of the mth Alternative

T^m = Total Weighted Risk Adjusted Threat Value of the mth Alternative

2. Acronyms in Pilot Study SAM Calculation Excel Sheet

Following acronyms have been used in the Pilot Study Excel sheet calculations:

a. Opportunity and Threat Factors

Opportunity and threat factors have used following acronyms in manufacturing, supply chain and general environment.

Manufacturing Environment Opportunities	**Acronym**
Reduction of Staff	ROS
Increased Productivity	IP
Improved Quality	IQ
New Product Development	NPD
Competitive Edge over Competitors	C.Edge
Increase in Market Share	IMKTSH
Supply Chain Environment Opportunities	
Long term Strategic Relationship	LSR
Sharing of Risk & Rewards	SRR
Joint Continuous Improvement	JCI
Product Volume Flexibility	PVF
General Environment Opportunities	
Benefit from Govt. Regulations	BGR
National/Intl Prominence	NINTLP
Operation & Support	OS
Manufacturing Environment Threats	
Staff Resistance to Change	SRC
Training Expenses	TE
Employee Layoff	EL
System Integration	SI
Technology Maturity	TM
Industrial Action	IA

Supply Chain Environment Threats	
Inadequate Technology	INAT
Technical Ability	TA
Knowledge of Business Opportunities	KBO
Commitment to Innovation	CI
Communication Gap	CG
General Environment Threats	
Lean Economy	LE
Life Cycle Analysis	LCA
Return on Investment	ROI

b. Technology Acronym

The technology alternatives have been called alternative A, B and C in excel sheet according to table shown below:

Risk Adjusted Strategic Value for Robot Based Technology	Alternative A
Risk Adjusted Strategic Value Server Driven Flexible Technology	Alternative B
Risk Adjusted Strategic Value for Existing Technology	Alternative C

Step 1: **(Opportunities)** **BAG IN BOX**

e(max) 1.099

Step 2:

K 0.91

Step3:

Manufacturing Environment

Factor	A	B	C	SUM	A	B	C
ROS	0.3	0.3	0.2	0.8	0.375	0.375	0.25
IP	0.9	0.8	0.3	2	0.45	0.4	0.15
IQ	0.8	0.8	0.4	2	0.4	0.4	0.2
NPD	0.9	0.9	0.2	2	0.45	0.45	0.1
C.Edge	0.9	0.9	0.2	2	0.45	0.45	0.1
IMKTSH	0.9	0.9	0.2	2	0.45	0.45	0.1

e(pu11) 0.985 e(pu12) 0.92 e(pu13) 0.96 e(pu14) 0.864

e(pu15) 0.864 e(pu16) 0.864

Supply Chain Environment

Factor	A	B	C	SUM	A	B	C
LSR	0.6	0.7	0.2	1.5	0.4	0.467	0.133
SRR	0.3	0.4	0.2	0.9	0.333	0.444	0.222
JCI	0.5	0.5	0.2	1.2	0.417	0.417	0.167
PVF	0.4	0.4	0.4	1.2	0.333	0.333	0.333

e(pu21) 0.902 e(pu22) 0.966 e(pu23) 0.936 e(pu24) 1

General Environment

Factor	A	B	C	SUM	A	B	C
BGR	0.7	0.7	0.2	1.6	0.438	0.438	0.125
NINTLP	0.9	0.9	0.2	2	0.45	0.45	0.1
OS	0.5	0.8	0.6	1.9	0.263	0.421	0.316

e(pu31) 0.895 e(pu32) 0.864 e(pu33) 0.983

Step4:

E(First Env) 5.456 E(Second Env) 3.803 E(Third Env) 2.741

Step5:

First Environment

F(u11)	0.027	F(U12)	0.148	F(U13)	0.073	F(U14)	0.251
F(U15)	0.251	F(U16)	0.251				

Second Environment

F(u21)	0.499	F(U22)	0.175	F(U23)	0.326	F(U24)	1E-15

Third Environment

F(U31)	0.406	F(U32)	0.527	F(U33)	0.067

Step6:

w11	w12	w13	w14	w15	w16	w21
0.037	0.155	0.235	0.236	0.216	0.121	0.424
w22	w23	w24	w31	w32	w33	
0.179	0.338	0.059	0.236	0.082	0.682	

F'(U11)	0.006	F'(U12)	0.124	F'(U13)	0.093	F'(U14)	0.32
F'(U15)	0.293	F'(U16)	0.164	F'(U21)	0.599	F'(U22)	0.089
F'(U23)	0.312	F'(U24)	2E-16				
F'(U31)	0.518	F'(U32)	0.234	F'(U33)	0.248		

Step 7:

Risk Aversion Factor

First Env		Second Env		Third Env	
ROS	0.04	LSR	0.4	BGR	0.3
IP	0.2	SRR	0.2	NINTLF	0.1
IQ	0.4	JCI	0.3	OS	0.7
NPD	0.3	PVF	0.06		
C.Edge	0.2				
IMKTSH	0.1				

Step8:

First Env weight	Second Env weigh	Thrid Env weight
0.28	0.627	0.094

First Alternative(A) wrt First Env
U 0.245

First Alternative(A) wrt Second Env
U 0.313

First Alternative(A) wrt Third Env
U 0.062

Risk Adjusted Opportunity Value for Alternative A 0.62

Second Alternative (B) wrt First Env
U 0.241

Second Alternative (B) wrt 2nd Env
U 0.358

Second Alternative (B) wrt 3rd Env
U 0.069

Risk Adjusted Opportunity Value for Alternative B 0.668

Third Alternative (C) wrt First Env
U 0.059

Third Alternative (C) wrt 2nd Env
U 0.109

Third Alternative (C) wrt 3rd Env
U 0.025

Risk Adjusted Opportunity Value for Alternative C 0.193

Step 1: **(Threats)** **BAG IN BOX**

e(max) 1.099

Step 2:

K 0.91

Step3:

Manufacturing Environment

Factor	A	B	C	SUM	A	B	C
SRC	0.3	0.2	0.1	0.6	0.5	0.333	0.167
TE	0.5	0.4	0.1	1	0.5	0.4	0.1
EL	0.4	0.4	0.1	0.9	0.444	0.444	0.111
SI	0.3	0.2	0.6	1.1	0.273	0.182	0.545
TM	0.3	0.2	0.2	0.7	0.429	0.286	0.286
IA	0.1	0.1	0.1	0.3	0.333	0.333	0.333

e(pu11) 0.921 e(pu12) 0.859 e(pu13) 0.878 e(pu14) 0.906

e(pu15) 0.982 e(pu16) 1

Supply Chain Environment

Factor	A	B	C	SUM	A	B	C
INAT	0.1	0.1	0.3	0.5	0.2	0.2	0.6
TA	0.3	0.3	0.2	0.8	0.375	0.375	0.25
KBO	0.2	0.2	0.1	0.5	0.4	0.4	0.2
CI	0.5	0.5	0.1	1.1	0.455	0.455	0.091
CG	0.2	0.2	0.1	0.5	0.4	0.4	0.2

e(pu21) 0.865 e(pu22) 0.985 e(pu23) 0.96 e(pu24) 0.851

e(pu25) 0.96

General Environment

Factor	A	B	C	SUM	A	B	C
LE	0.4	0.4	0.1	0.9	0.444	0.444	0.111
LCA	0.1	0.3	0.3	0.7	0.143	0.429	0.429
ROI	0.1	0.1	0.1	0.3	0.333	0.333	0.333

e(pu31) 0.878 e(pu32) 0.914 e(pu33) 1

Step4:

E(First Env) 5.545 E(Second Env) 4.621 E(Third Env) 2.792

Step5:

First Environment

F(u11)	0.175	F(U12)	0.311	F(U13)	0.268	F(U14)	0.208
F(U15)	0.039	F(U16)	5E-16				

Second Environment

F(u21)	0.357	F(U22)	0.039	F(U23)	0.105	F(U24)	0.394
F(U25)	0.105						

Third Environment

F(U31)	0.586	F(U32)	0.414	F(U33)	1E-15

Step6:

w11	w12	w13	w14	w15	w16	w21
0.297	0.089	0.12	0.033	0.415	0.047	0.131
w22	w23	w24	w25	w31	w32	w33
0.252	0.51	0.068	0.039	0.135	0.71	0.155

F'(U11)	0.385	F'(U12)	0.205	F'(U13)	0.238	F'(U14)	0.051
F'(U15)	0.121	F'(U16)	2E-16	F'(U21)	0.331	F'(U22)	0.07
F'(U23)	0.38	F'(U24)	0.19	F'(U25)	0.029		
F'(U31)	0.212	F'(U32)	0.788	F'(U33)	4E-16		

Step 7:

Risk Aversion Factor

First Env		Second Env		Third Env	
SRC	0.3	INAT	0.1	LE	0.1
TE	0.09	TA	0.3	LCA	0.2
EL	0.1	KBO	0.5	ROI	0.7
SI	0.04	CI	0.07		
TM	0.4	CG	0.04		
IA	0.05				

Step8:

First Env weight	Second Env weig	Thrid Env weight
0.28	0.627	0.094

First Alternative(A) wrt First Env
T -0.11

First Alternative(A) wrt Second Env
T -0.16

First Alternative(A) wrt Third Env
T -0.02

Risk Adjusted Threat Value for Alternative A -0.284

Second Alternative (B) wrt First Env
T -0.09

Second Alternative (B) wrt 2nd Env
T -0.16

Second Alternative (B) wrt 3rd Env
T -0.03

Risk Adjusted Threat Value for Alternative B -0.277

Third Alternative (C) wrt First Env
T -0.04

Third Alternative (C) wrt 2nd Env
T -0.12

Third Alternative (C) wrt 3rd Env
T -0.03

Risk Adjusted Threat Value for Alternative C -0.186

Appendix H

Case Study

1. Strategic Assessment Model (SAM) Calculations

The calculations for determination of strategic assessment of technology alternative are carried out exactly in the same manner as described in Appendix G. Therefore the equations and process for calculation is not repeated.

2. Acronyms in Case Study SAM Calculation Excel Sheet

Following acronyms have been used in the Pilot Study Excel sheet calculations:

a. Opportunity and Threat Factors

Opportunity and threat factors have used following acronyms in manufacturing, supply chain and general environment.

Manufacturing Environment Opportunities	**Acronym**
Development Cost Reduction	DCR
Development Time Reduction	DTR
Unit Cost Reduction	UCR
Maintenance Cost	MCR
Consumable Cost	CCR
Design Enabler/Flexibility	DE/DF
Increased Productivity	IP
Quality Levels	QL
Performance Enhancement	PE
Intellectual Property Potential	IPR
Supply Chain Environment Opportunities	
Ability to Influence Shape and Demand	AID
Ability to Handle Demand Flexibility	AHDF
Machine Effectiveness	ME

Sensitivity to Raw Materials	STR
Lead Time Reduction	LTR
Lean Operations/Manufacturing	LOP
General Environment Opportunities	
Benefits from Government Regulations	BGR
Ease of Conforming with HSE Legislation	EHSE
Ease of Technology Forecasting	ETFC
Manufacturing Environment Threats	
Capital Cost	CC
Staff Resistance to Change	SRC
Training Expenses	TE
System Integration	SI
Technology Maturity	TM
Potential New Equipment Installation/ Re-Location	PNE/RL
Part Transfer/ Manufacturing Change Request	MCR
Supply Chain Environment Threats	
Inadequate Technology	IAT
Technical Ability	TA
Knowledge of Business Opportunities	KBO
Commitment to Innovation	CI
Financial Constraints	FC
Technology Strategy	TS
General Environment Threats	
Life Cycle Analysis	LCA
Return on Investment	ROI
Change of Government Regulations	CGR
Technology Uncertainty	TU

b. Technology Acronym

The technology alternatives have been called alternative A, B and C in excel sheet according to table shown below:

Name of Technology	Acronym
Laser	Laser
Electron Beam Welding	EBW
Friction Stir Welding	FSW
Plasma	Plasma
Shaped Metal Deposition	SMD
Direct Laser Deposition	DLD
Linear Friction Welding	LFW
Rotary Friction Welding	RFW
Isostatic	Isostatic

Step 1: **(Opportunities)** **Engine Component No.1**

e(max) 2.197

Step 2:

K 0.455

Step3:

Manufacturing Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati
DCR	0.7	0.9	0.8	0.6	0.7	0.6	0.7	0.7	0.9	6.6	0.106	0.136	0.121	0.091	0.106	0.091	0.106	0.106	0.136
DTR	0.5	0.5	0.7	0.8	0.6	0.6	0.5	0.5	0.5	5.2	0.096	0.096	0.135	0.154	0.115	0.115	0.096	0.096	0.096
UCR	0.6	0.9	0.9	0.5	0.7	0.5	0.7	0.7	0.5	6	0.1	0.15	0.15	0.083	0.117	0.083	0.117	0.117	0.083
MCR	0.7	0.8	0.5	0.6	0.6	0.7	0.7	0.7	0.5	5.8	0.121	0.138	0.086	0.103	0.103	0.121	0.121	0.121	0.086
CCR	0.5	0.5	0.5	0.5	0.7	0.5	0.5	0.5	0.5	4.7	0.106	0.106	0.106	0.106	0.149	0.106	0.106	0.106	0.106
DE/DF	0.6	0.6	0.6	0.6	0.7	0.7	0.6	0.6	0.6	5.6	0.107	0.107	0.107	0.107	0.125	0.125	0.107	0.107	0.107
IP	0.6	0.6	0.9	0.6	0.6	0.5	0.6	0.6	0.5	5.5	0.109	0.109	0.164	0.109	0.109	0.091	0.109	0.109	0.091
QL	0.6	0.7	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.9	0.102	0.119	0.136	0.102	0.102	0.102	0.119	0.119	0.102
PE	0.5	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6	5.4	0.093	0.111	0.13	0.111	0.111	0.111	0.111	0.111	0.111
IPR	0.5	0.5	0.2	0.5	0.6	0.6	0.5	0.5	0.6	4.5	0.111	0.111	0.044	0.111	0.133	0.133	0.111	0.111	0.133
e(pu11)	0.995		e(pu12)	0.993		e(pu13)	0.989		e(pu14)	0.995		e(pu15)	0.997		e(pu16)	0.999		e(pu17)	0.993
e(pu18)	0.998		e(pu19)	0.999		e(pu20)	0.985												

Supply Chain Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati
AID	0.5	0.5	0.6	0.5	0.6	0.6	0.6	0.6	0.6	5.1	0.098	0.098	0.118	0.098	0.118	0.118	0.118	0.118	0.118
AHDF	0.8	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6.2	0.129	0.097	0.129	0.113	0.113	0.097	0.113	0.113	0.097
ME	0.6	0.5	0.9	0.8	0.8	0.8	0.8	0.8	0.8	6.8	0.088	0.074	0.132	0.118	0.118	0.118	0.118	0.118	0.118
STR	0.6	0.6	0.5	0.6	0.6	0.7	0.5	0.5	0.6	5.2	0.115	0.115	0.096	0.115	0.115	0.135	0.096	0.096	0.115
LTR	0.6	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6	0.1	0.1	0.133	0.117	0.117	0.1	0.117	0.117	0.1
LOP	0.6	0.6	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.8	0.103	0.103	0.138	0.103	0.103	0.103	0.121	0.121	0.103
e(pu21)	0.998		e(pu22)	0.997		e(pu23)	0.994		e(pu24)	0.997		e(pu25)	0.998		e(pu26)	0.998			

General Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati
BGR	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.085	0.085	0.136	0.136	0.102
EHSE	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.085	0.085	0.136	0.136	0.102
ETFC	0.8	0.8	0.7	0.8	0.5	0.5	0.5	0.5	0.5	5.6	0.143	0.143	0.125	0.143	0.089	0.089	0.089	0.089	0.089
e(pu31)	0.989		e(pu32)	0.989		e(pu33)	0.989												

Step4: E(First Env) 9.943 E(Second Env 5.983 E(Third Env) 2.968

Step5:

First Environment

F(U11)	0.081	F(U12)	0.12	F(U13)	0.197	F(U14)	0.089	F(U15)	0.053	F(U16)	0.017	F(U17)	0.118
F(U18)	0.042	F(U19)	0.025	F(U20)	0.257								

Second Environment

F(U21)	0.092	F(U22)	0.149	F(U23)	0.334	F(U24)	0.154	F(U25)	0.129	F(U26)	0.142

Third Environment

F(U31)	0.326	F(U32)	0.326	F(U33)	0.348

Step6:

w11	w12	w13	w14	w15	w16	w17	w18	w19	w10	w21	w22	w23	w24	w25	w26	w31	w32	w33
0.055	0.055	0.123	0.049	0.037	0.078	0.237	0.197	0.101	0.068	0.072	0.21	0.242	0.058	0.231	0.187	0.14	0.333	0.528

F'(U11)	0.045	F'(U12)	0.067	F'(U13)	0.243	F'(U14)	0.044	F'(U15)	0.02	F'(U16)	0.014	F'(U17)	0.283
F'(U18)	0.084	F'(U19)	0.025	F'(U20)	0.176	F'(U21)	0.036	F'(U22)	0.17	F'(U23)	0.44	F'(U24)	0.049
F'(U25)	0.162	F'(U26)	0.144	F'(U31)	0.135	F'(U32)	0.321	F'(U33)	0.544				

Step 7:

Risk Aversion Factor

First Env		Second Env		Third Env	
DCR	0.08	AID	0.2	BGR	0.2
DTR	0.08	AHDF	0.8	EHSE	0.6
UCR	0.8	ME	0.8	ETFC	0.8
MCR	0.08	STR	0.08		
CCR	0.08	LTR	0.8		
DE/DF	0.2	LOP	0.4		
IP	0.8				
QL	0.8				
PE	0.4				
IPR	0.2				

Step8:

First Env weight	Second Env wı	Thrid Env weight
0.634	0.192	0.174

Laser wrt First Env		Laser wrt Second Env		Laser wrt Third Env	
U	0.325	U	0.106	U	0.112
		Risk Adjusted Opportunity Value for Laser	**0.542**		
EBW wrt First Env		EBW wrt 2nd Env		EBW wrt 3rd Env	
U	0.396	U	0.09	U	0.12
		Risk Adjusted Opportunity Value for EBW	**0.606**		
FSW wrt First Env		FSW wrt 2nd Env		FSW wrt 3rd Env	
U	0.432	U	0.148	U	0.127
		Risk Adjusted Opportunity Value for FSW	**0.707**		
Plasma wrt First Env		Plasma wrt 2nd Env		Plasma wrt 3rd Env	
U	0.318	U	0.124	U	0.104
		Risk Adjusted Opportunity Value for Plasma	**0.546**		
SMD wrt First Env		SMD wrt 2nd Env		SMD wrt 3rd Env	
U	0.359	U	0.125	U	0.073
		Risk Adjusted Opportunity Value for SMD	**0.557**		
DLD wrt First Env		DLD wrt 2nd Env		DLD wrt 3rd Env	
U	0.307	U	0.119	U	0.073
		Risk Adjusted Opportunity Value for DLD	**0.499**		
LFW wrt First Env		LFW wrt 2nd Env		LFW wrt 3rd Env	
U	0.349	U	0.127	U	0.098
		Risk Adjusted Opportunity Value for LFW	**0.574**		
RFW wrt First Env		RFW wrt 2nd Env		RFW wrt 3rd Env	
U	0.349	U	0.127	U	0.098
		Risk Adjusted Opportunity Value for RFW	**0.574**		
Isostatic wrt First Env		Isostatic wrt 2nd Env		Isostatic wrt 3rd Env	
U	0.305	U	0.118	U	0.081
		Risk Adjusted Opportunity Value for Isostatic	**0.504**		

Step 1: **(Opportunities)** **Engine Component No.2**

e(max) 2.197

Step 2:

K 0.455

Step3:

Manufacturing Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostatic
DCR	0.2	0.9	0.5	0.6	0.9	0.9	0.7	0.5	0.9	6.1	0.033	0.148	0.082	0.098	0.148	0.148	0.115	0.082	0.148
DTR	0.8	0.8	0.5	0.8	0.9	0.9	0.6	0.5	0.8	6.6	0.121	0.121	0.076	0.121	0.136	0.136	0.091	0.076	0.121
UCR	0.9	0.9	0.7	0.5	0.9	0.8	0.7	0.5	0.9	6.8	0.132	0.132	0.103	0.074	0.132	0.118	0.103	0.074	0.132
MCR	0.7	0.8	0.5	0.6	0.6	0.7	0.7	0.7	0.5	5.8	0.121	0.138	0.086	0.103	0.103	0.121	0.121	0.121	0.086
CCR	0.5	0.5	0.5	0.5	0.7	0.5	0.5	0.5	0.5	4.7	0.106	0.106	0.106	0.106	0.149	0.106	0.106	0.106	0.106
DE/DF	0.6	0.6	0.6	0.6	0.7	0.7	0.6	0.6	0.6	5.6	0.107	0.107	0.107	0.107	0.125	0.125	0.107	0.107	0.107
IP	0.9	0.9	0.5	0.6	0.9	0.8	0.6	0.5	0.8	6.5	0.138	0.138	0.077	0.092	0.138	0.123	0.092	0.077	0.123
QL	0.6	0.7	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.9	0.102	0.119	0.136	0.102	0.102	0.102	0.119	0.119	0.102
PE	0.5	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6	5.4	0.093	0.111	0.13	0.111	0.111	0.111	0.111	0.111	0.111
IPR	0.5	0.5	0.2	0.5	0.6	0.6	0.5	0.5	0.6	4.5	0.111	0.111	0.044	0.111	0.133	0.133	0.111	0.111	0.133

e(pu11) 0.969 e(pu12) 0.99 e(pu13) 0.99 e(pu14) 0.995 e(pu15) 0.997 e(pu16) 0.999

e(pu17) 0.988 e(pu18) 0.998 e(pu19) 0.999 e(pu20) 0.985

Supply Chain Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostatic
AID	0.5	0.5	0.6	0.5	0.6	0.6	0.6	0.6	0.6	5.1	0.098	0.098	0.118	0.098	0.118	0.118	0.118	0.118	0.118
AHDF	0.8	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6.2	0.129	0.097	0.129	0.113	0.113	0.097	0.113	0.113	0.097
ME	0.6	0.5	0.9	0.8	0.8	0.8	0.8	0.8	0.8	6.8	0.088	0.074	0.132	0.118	0.118	0.118	0.118	0.118	0.118
STR	0.6	0.6	0.5	0.6	0.6	0.7	0.5	0.5	0.6	5.2	0.115	0.115	0.096	0.115	0.115	0.135	0.096	0.096	0.115
LTR	0.6	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6	0.1	0.1	0.133	0.117	0.117	0.1	0.117	0.117	0.1
LOP	0.6	0.6	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.8	0.103	0.103	0.138	0.103	0.103	0.103	0.121	0.121	0.103

e(pu21) 0.998 e(pu22) 0.997 e(pu23) 0.994 e(pu24) 0.997 e(pu25) 0.998 e(pu26) 0.998

General Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostatic
BGR	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.085	0.085	0.136	0.136	0.102
EHSE	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.085	0.085	0.136	0.136	0.102
ETFC	0.8	0.8	0.7	0.8	0.5	0.5	0.5	0.5	0.5	5.6	0.143	0.143	0.125	0.143	0.089	0.089	0.089	0.089	0.089

e(pu31) 0.989 e(pu32) 0.989 e(pu33) 0.989

Step4: E(First Env) 9.909 E(Second Env 5.983 E(Third Env) 2.968

Step5:

First Environment

F(U11)	0.345	F(U12)	0.109	F(U13)	0.114	F(U14)	0.056	F(U15)	0.033	F(U16)	0.011	F(U17)	0.129
F(U18)	0.027	F(U19)	0.015	F(U20)	0.161								

Second Environment

F(U21)	0.092	F(U22)	0.149	F(U23)	0.334	F(U24)	0.154	F(U25)	0.129	F(U26)	0.142

Third Environment

F(U31)	0.326	F(U32)	0.326	F(U33)	0.348

Step6:

w11	w12	w13	w14	w15	w16	w17	w18	w19	w10	w21	w22	w23	w24	w25	w26	w31	w32	w33
0.055	0.055	0.123	0.049	0.037	0.078	0.237	0.197	0.101	0.068	0.072	0.21	0.242	0.058	0.231	0.187	0.14	0.333	0.528

F'(U11)	0.206	F'(U12)	0.065	F'(U13)	0.153	F'(U14)	0.03	F'(U15)	0.013	F'(U16)	0.009	F'(U17)	0.331
F'(U18)	0.057	F'(U19)	0.017	F'(U20)	0.119	F'(U21)	0.036	F'(U22)	0.17	F'(U23)	0.44	F'(U24)	0.049
F'(U25)	0.162	F'(U26)	0.144	F'(U31)	0.135	F'(U32)	0.321	F'(U33)	0.544				

Step 7:

Risk Aversion Factor

First Env		Second Env		Third Env	
DCR	0.08	AID	0.2	BGR	0.2
DTR	0.08	AHDF	0.8	EHSE	0.6
UCR	0.8	ME	0.8	ETFC	0.8
MCR	0.08	STR	0.08		
CCR	0.08	LTR	0.8		
DE/DF	0.2	LOP	0.4		
IP	0.8				
QL	0.8				
PE	0.4				
IPR	0.2				

Step8:

First Env weight	Second Env weigl	Thrid Env weight
0.634	0.192	0.174

Laser wrt First Env	Laser wrt Second Env	Laser wrt Third Env
U 0.4	U 0.106	U 0.112
	Risk Adjusted Opportunity Value for Laser 0.618	
EBW wrt First Env	EBW wrt 2nd Env	EBW wrt 3rd Env
U 0.498	U 0.09	U 0.12
	Risk Adjusted Opportunity Value for EBW 0.708	
FSW wrt First Env	FSW wrt 2nd Env	FSW wrt 3rd Env
U 0.292	U 0.148	U 0.127
	Risk Adjusted Opportunity Value for FSW 0.567	
Plasma wrt First Env	Plasma wrt 2nd Env	Plasma wrt 3rd Env
U 0.333	U 0.124	U 0.104
	Risk Adjusted Opportunity Value for Plasma 0.561	
SMD wrt First Env	SMD wrt 2nd Env	SMD wrt 3rd Env
U 0.505	U 0.125	U 0.073
	Risk Adjusted Opportunity Value for SMD 0.703	
DLD wrt First Env	DLD wrt 2nd Env	DLD wrt 3rd Env
U 0.465	U 0.119	U 0.073
	Risk Adjusted Opportunity Value for DLD 0.657	
LFW wrt First Env	LFW wrt 2nd Env	LFW wrt 3rd Env
U 0.363	U 0.127	U 0.098
	Risk Adjusted Opportunity Value for LFW 0.588	
RFW wrt First Env	RFW wrt 2nd Env	RFW wrt 3rd Env
U 0.292	U 0.127	U 0.098
	Risk Adjusted Opportunity Value for RFW 0.517	
Isostatic wrt First Env	Isostatic wrt 2nd Env	Isostatic wrt 3rd Env
U 0.469	U 0.118	U 0.081
	Risk Adjusted Opportunity Value for Isostatic 0.668	

Step 1: **(Opportunities)** **Engine Component No.3**

e(max) 2.197

Step 2:

K 0.455

Step3:

Manufacturing Environment

Factor	Laser	EBW	FSW	Plasm	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati(
DCR	0.8	0.9	0.8	0.6	0.8	0.7	0.7	0.7	0.9	6.9	0.116	0.13	0.116	0.087	0.12	0.101	0.101	0.101	0.13
DTR	0.6	0.6	0.7	0.8	0.7	0.7	0.6	0.5	0.6	5.8	0.103	0.103	0.121	0.138	0.12	0.121	0.103	0.086	0.103
UCR	0.7	0.9	0.9	0.5	0.8	0.6	0.7	0.7	0.6	6.4	0.109	0.141	0.141	0.078	0.13	0.094	0.109	0.109	0.094
MCR	0.7	0.8	0.5	0.6	0.6	0.7	0.7	0.7	0.5	5.8	0.121	0.138	0.086	0.103	0.1	0.121	0.121	0.121	0.086
CCR	0.5	0.5	0.5	0.5	0.7	0.5	0.5	0.5	0.5	4.7	0.106	0.106	0.106	0.106	0.15	0.106	0.106	0.106	0.106
DE/DF	0.6	0.6	0.6	0.6	0.7	0.7	0.6	0.6	0.6	5.6	0.107	0.107	0.107	0.107	0.13	0.125	0.107	0.107	0.107
IP	0.7	0.6	0.8	0.6	0.6	0.6	0.6	0.6	0.6	5.7	0.123	0.105	0.14	0.105	0.11	0.105	0.105	0.105	0.105
QL	0.6	0.7	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.9	0.102	0.119	0.136	0.102	0.1	0.102	0.119	0.119	0.102
PE	0.5	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6	5.4	0.093	0.111	0.13	0.111	0.11	0.111	0.111	0.111	0.111
IPR	0.5	0.5	0.2	0.5	0.6	0.6	0.5	0.5	0.6	4.5	0.111	0.111	0.044	0.111	0.13	0.133	0.111	0.111	0.133

e(pu11) 0.997 e(pu12) 0.996 e(pu13) 0.993 e(pu14) 0.995 e(pu15) 0.997 e(pu16) 0.999 e(pu17) 0.998

e(pu18) 0.998 e(pu19) 0.999 e(pu20) 0.985

Supply Chain Environment

Factor	Laser	EBW	FSW	Plasm	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati(
AID	0.5	0.5	0.6	0.5	0.6	0.6	0.6	0.6	0.6	5.1	0.098	0.098	0.118	0.098	0.12	0.118	0.118	0.118	0.118
AHDF	0.8	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6.2	0.129	0.097	0.129	0.113	0.11	0.097	0.113	0.113	0.097
ME	0.6	0.5	0.9	0.8	0.8	0.8	0.8	0.8	0.8	6.8	0.088	0.074	0.132	0.118	0.12	0.118	0.118	0.118	0.118
STR	0.6	0.6	0.5	0.6	0.6	0.7	0.5	0.5	0.6	5.2	0.115	0.115	0.096	0.115	0.12	0.135	0.096	0.096	0.115
LTR	0.6	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6	0.1	0.1	0.133	0.117	0.12	0.1	0.117	0.117	0.1
LOP	0.6	0.6	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.8	0.103	0.103	0.138	0.103	0.1	0.103	0.121	0.121	0.103

e(pu21) 0.998 e(pu22) 0.997 e(pu23) 0.994 e(pu24) 0.997 e(pu25) 0.998 e(pu26) 0.998

General Environment

Factor	Laser	EBW	FSW	Plasm	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati(
BGR	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.08	0.085	0.136	0.136	0.102
EHSE	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.08	0.085	0.136	0.136	0.102
ETFC	0.8	0.8	0.7	0.8	0.5	0.5	0.5	0.5	0.5	5.6	0.143	0.143	0.125	0.143	0.09	0.089	0.089	0.089	0.089

e(pu31) 0.989 e(pu32) 0.989 e(pu33) 0.989

Step4: E(First Env) 9.955 E(Second Env) 5.983 E(Third Env) 2.968

Step5:

First Environment

F(U11)	0.078	F(U12)	0.085	F(U13)	0.167	F(U14)	0.114	F(U15)	0.067	F(U16	0.022	F(U17)	0.053
F(U18)	0.054	F(U19)	0.032	F(U20)	0.328								

Second Environment

F(U21)	0.092	F(U22)	0.149	F(U23)	0.334	F(U24)	0.154	F(U25)	0.129	F(U26	0.142

Third Environment

F(U31)	0.326	F(U32)	0.326	F(U33)	0.348

Step6:

w11	w12	w13	w14	w15	w16	w17	w18	w19	w10	w21	w22	w23	w24	w25	w26	w31	w32	w33
0.055	0.055	0.123	0.049	0.037	0.078	0.237	0.197	0.101	0.068	0.072	0.21	0.242	0.058	0.231	0.19	0.14	0.333	0.528

F'(U11)	0.048	F'(U12)	0.053	F'(U13)	0.234	F'(U14)	0.063	F'(U15)	0.028	F'(U16)	0.02	F'(U17)	0.143
F'(U18)	0.121	F'(U19)	0.036	F'(U20)	0.253	F'(U21)	0.036	F'(U22)	0.17	F'(U23)	0.44	F'(U24)	0.049
F'(U25)	0.162	F'(U26)	0.144	F'(U31)	0.135	F'(U32)	0.321	F'(U33)	0.544				

Step 7:

Risk Aversion Factor

First Env		Second Env		Third Env	
DCR	0.08	AID	0.2	BGR	0.2
DTR	0.08	AHDF	0.8	EHSE	0.6
UCR	0.8	ME	0.8	ETFC	0.8
MCR	0.08	STR	0.08		
CCR	0.08	LTR	0.8		
DE/DF	0.2	LOP	0.4		
IP	0.8				
QL	0.8				
PE	0.4				
IPR	0.2				

Step8:

First Env weight	Second Env we	Thrid Env weight
0.634	0.192	0.174

Laser wrt First Env		Laser wrt Second Env			Laser wrt Third Env	
U	0.358	U	0.106		U	0.112
		Risk Adjusted Opportunity Value for Laser		**0.576**		
EBW wrt First Env		EBW wrt 2nd Env			EBW wrt 3rd Env	
U	0.403	U	0.09		U	0.12
		Risk Adjusted Opportunity Value for EBW		**0.613**		
FSW wrt First Env		FSW wrt 2nd Env			FSW wrt 3rd Env	
U	0.376	U	0.148		U	0.127
		Risk Adjusted Opportunity Value for FSW		**0.652**		
Plasma wrt First Env		Plasma wrt 2nd Env			Plasma wrt 3rd Env	
U	0.317	U	0.124		U	0.104
		Risk Adjusted Opportunity Value for Plasma		**0.545**		
SMD wrt First Env		SMD wrt 2nd Env			SMD wrt 3rd Env	
U	0.389	U	0.125		U	0.073
		Risk Adjusted Opportunity Value for SMD		**0.587**		
DLD wrt First Env		DLD wrt 2nd Env			DLD wrt 3rd Env	
U	0.353	U	0.119		U	0.073
		Risk Adjusted Opportunity Value for DLD		**0.545**		
LFW wrt First Env		LFW wrt 2nd Env			LFW wrt 3rd Env	
U	0.356	U	0.127		U	0.098
		Risk Adjusted Opportunity Value for LFW		**0.581**		
RFW wrt First Env		RFW wrt 2nd Env			RFW wrt 3rd Env	
U	0.353	U	0.127		U	0.098
		Risk Adjusted Opportunity Value for RFW		**0.578**		
Isostatic wrt First Env		Isostatic wrt 2nd Env			Isostatic wrt 3rd Env	
U	0.346	U	0.118		U	0.081
		Risk Adjusted Opportunity Value for Isostatic		**0.545**		

Step 1: **(Opportunities)** **Engine Component No.4**

e(max) 2.197

Step 2:

K 0.455

Step3:

Manufacturing Environment

Factor	Laser	EBW	FSW	Plasm	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati
DCR	0.9	0.9	0.6	0.6	0.9	0.8	0.7	0.5	0.9	6.8	0.132	0.132	0.088	0.088	0.132	0.118	0.103	0.074	0.132
DTR	0.7	0.7	0.5	0.8	0.8	0.8	0.6	0.5	0.7	6.1	0.115	0.115	0.082	0.131	0.131	0.131	0.098	0.082	0.115
UCR	0.8	0.9	0.8	0.5	0.9	0.7	0.7	0.5	0.7	6.5	0.123	0.138	0.123	0.077	0.138	0.108	0.108	0.077	0.108
MCR	0.7	0.8	0.5	0.6	0.6	0.7	0.7	0.7	0.5	5.8	0.121	0.138	0.086	0.103	0.103	0.121	0.121	0.121	0.086
CCR	0.5	0.5	0.5	0.5	0.7	0.5	0.5	0.5	0.5	4.7	0.106	0.106	0.106	0.106	0.149	0.106	0.106	0.106	0.106
DE/DF	0.6	0.6	0.6	0.6	0.7	0.7	0.6	0.6	0.6	5.6	0.107	0.107	0.107	0.107	0.125	0.125	0.107	0.107	0.107
IP	0.8	0.8	0.6	0.6	0.8	0.7	0.6	0.5	0.7	6.1	0.131	0.131	0.098	0.098	0.131	0.115	0.098	0.082	0.115
QL	0.6	0.7	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.9	0.102	0.119	0.136	0.102	0.102	0.102	0.119	0.119	0.102
PE	0.5	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6	5.4	0.093	0.111	0.13	0.111	0.111	0.111	0.111	0.111	0.111
IPR	0.5	0.5	0.2	0.5	0.6	0.6	0.5	0.5	0.6	4.5	0.111	0.111	0.044	0.111	0.133	0.133	0.111	0.111	0.133
e(pu11)	0.991		e(pu12)	0.993		e(pu13)	0.991		e(pu14)	0.995		e(pu15)	0.997		e(pu16)	0.999		e(pu17)	0.995
e(pu18)	0.998		e(pu19)	0.999		e(pu20)	0.985												

Supply Chain Environment

Factor	Laser	EBW	FSW	Plasm	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati
AID	0.5	0.5	0.6	0.5	0.6	0.6	0.6	0.6	0.6	5.1	0.098	0.098	0.118	0.098	0.118	0.118	0.118	0.118	0.118
AHDF	0.8	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6.2	0.129	0.097	0.129	0.113	0.113	0.097	0.113	0.113	0.097
ME	0.6	0.5	0.9	0.8	0.8	0.8	0.8	0.8	0.8	6.8	0.088	0.074	0.132	0.118	0.118	0.118	0.118	0.118	0.118
STR	0.6	0.6	0.5	0.6	0.6	0.7	0.5	0.5	0.6	5.2	0.115	0.115	0.096	0.115	0.115	0.135	0.096	0.096	0.115
LTR	0.6	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6	0.1	0.1	0.133	0.117	0.117	0.1	0.117	0.117	0.1
LOP	0.6	0.6	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.8	0.103	0.103	0.138	0.103	0.103	0.103	0.121	0.121	0.103
e(pu21)	0.998		e(pu22)	0.997		e(pu23)	0.994		e(pu24)	0.997		e(pu25)	0.998		e(pu26)	0.998			

General Environment

Factor	Laser	EBW	FSW	Plasm	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati
BGR	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.085	0.085	0.136	0.136	0.102
EHSE	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.085	0.085	0.136	0.136	0.102
ETFC	0.8	0.8	0.7	0.8	0.5	0.5	0.5	0.5	0.5	5.6	0.143	0.143	0.125	0.143	0.089	0.089	0.089	0.089	0.089
e(pu31)	0.989		e(pu32)	0.989		e(pu33)	0.989												

Step4: E(First Env) 9.942 E(Second Env 5.983 E(Third Env) 2.968

Step5:

First Environment

F(U11)	0.161	F(U12)	0.114	F(U13)	0.153	F(U14)	0.088	F(U15	0.052	F(U16	0.017	F(U17	0.093
F(U18)	0.042	F(U19)	0.024	F(U20)	0.254								

Second Environment

F(U21)	0.092	F(U22)	0.149	F(U23)	0.334	F(U24)	0.154	F(U25	0.129	F(U26	0.142

Third Environment

F(U31)	0.326	F(U32)	0.326	F(U33)	0.348

Step6:

w11	w12	w13	w14	w15	w16	w17	w18	w19	w10	w21	w22	w23	w24	w25	w26	w31	w32	w33
0.055	0.055	0.123	0.049	0.037	0.078	0.237	0.197	0.101	0.068	0.072	0.21	0.242	0.058	0.231	0.187	0.14	0.333	0.528

F'(U11)	0.097	F'(U12)	0.069	F'(U13)	0.206	F'(U14)	0.047	F'(U15)	0.021	F'(U16)	0.015	F'(U17)	0.24
F'(U18)	0.09	F'(U19)	0.027	F'(U20)	0.189	F'(U21)	0.036	F'(U22)	0.17	F'(U23)	0.44	F'(U24)	0.049
F'(U25)	0.162	F'(U26)	0.144	F'(U31)	0.135	F'(U32)	0.321	F'(U33)	0.544				

Step 7:

Risk Aversion Factor

First Env		Second Env		Third Env	
DCR	0.08	AID	0.2	BGR	0.2
DTR	0.08	AHDF	0.8	EHSE	0.6
UCR	0.8	ME	0.8	ETFC	0.8
MCR	0.08	STR	0.08		
CCR	0.08	LTR	0.8		
DE/DF	0.2	LOP	0.4		
IP	0.8				
QL	0.8				
PE	0.4				
IPR	0.2				

Step8:

First Env weight	Second Env wei(	Thrid Env weight
0.634	0.192	0.174

Laser wrt First Env		Laser wrt Second Env		Laser wrt Third Env
U 0.416		U 0.106		U 0.112
	Risk Adjusted Opportunity Value for Laser		**0.634**	
EBW wrt First Env		EBW wrt 2nd Env		EBW wrt 3rd Env
U 0.444		U 0.09		U 0.12
	Risk Adjusted Opportunity Value for EBW		**0.654**	
FSW wrt First Env		FSW wrt 2nd Env		FSW wrt 3rd Env
U 0.33		U 0.148		U 0.127
	Risk Adjusted Opportunity Value for FSW		**0.605**	
Plasma wrt First Env		Plasma wrt 2nd Env		Plasma wrt 3rd Env
U 0.324		U 0.124		U 0.104
	Risk Adjusted Opportunity Value for Plasma		**0.552**	
SMD wrt First Env		SMD wrt 2nd Env		SMD wrt 3rd Env
U 0.452		U 0.125		U 0.073
	Risk Adjusted Opportunity Value for SMD		**0.65**	
DLD wrt First Env		DLD wrt 2nd Env		DLD wrt 3rd Env
U 0.396		U 0.119		U 0.073
	Risk Adjusted Opportunity Value for DLD		**0.588**	
LFW wrt First Env		LFW wrt 2nd Env		LFW wrt 3rd Env
U 0.358		U 0.127		U 0.098
	Risk Adjusted Opportunity Value for LFW		**0.583**	
RFW wrt First Env		RFW wrt 2nd Env		RFW wrt 3rd Env
U 0.299		U 0.127		U 0.098
	Risk Adjusted Opportunity Value for RFW		**0.524**	
Isostatic wrt First Env		Isostatic wrt 2nd Env		Isostatic wrt 3rd Env
U 0.391		U 0.118		U 0.081
	Risk Adjusted Opportunity Value for Isostatic		**0.59**	

Step 1: **(Opportunities)** **Engine Component No.5**

e(max) 2.197

Step 2:

K 0.455

Step3:

Manufacturing Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostatic
DCR	0.9	0.9	0.6	0.6	0.9	0.9	0.7	0.5	0.9	6.9	0.13	0.13	0.087	0.087	0.13	0.13	0.101	0.072	0.13
DTR	0.8	0.8	0.5	0.8	0.9	0.9	0.6	0.5	0.8	6.6	0.121	0.121	0.076	0.121	0.136	0.136	0.091	0.076	0.121
UCR	0.9	0.9	0.8	0.5	0.9	0.8	0.7	0.5	0.8	6.8	0.132	0.132	0.118	0.074	0.132	0.118	0.103	0.074	0.118
MCR	0.7	0.8	0.5	0.6	0.6	0.7	0.7	0.7	0.5	5.8	0.121	0.138	0.086	0.103	0.103	0.121	0.121	0.121	0.086
CCR	0.5	0.5	0.5	0.5	0.7	0.5	0.5	0.5	0.5	4.7	0.106	0.106	0.106	0.106	0.149	0.106	0.106	0.106	0.106
DE/DF	0.6	0.6	0.6	0.6	0.7	0.7	0.6	0.6	0.6	5.6	0.107	0.107	0.107	0.107	0.125	0.125	0.107	0.107	0.107
IP	0.9	0.8	0.6	0.6	0.8	0.8	0.6	0.5	0.8	6.4	0.141	0.125	0.094	0.094	0.125	0.125	0.094	0.078	0.125
QL	0.6	0.7	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.9	0.102	0.119	0.136	0.102	0.102	0.102	0.119	0.119	0.102
PE	0.5	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6	5.4	0.093	0.111	0.13	0.111	0.111	0.111	0.111	0.111	0.111
IPR	0.5	0.5	0.2	0.5	0.6	0.6	0.5	0.5	0.6	4.5	0.111	0.111	0.044	0.111	0.133	0.133	0.111	0.111	0.133

e(pu11) 0.99 e(pu12) 0.99 e(pu13) 0.99 e(pu14) 0.99 e(pu15) 0.997 e(pu16) 0.999 e(pu17) 0.992

e(pu18) 0.998 e(pu19) 0.999 e(pu20) 0.985

Supply Chain Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostatic
AID	0.5	0.5	0.6	0.5	0.6	0.6	0.6	0.6	0.6	5.1	0.098	0.098	0.118	0.098	0.118	0.118	0.118	0.118	0.118
AHDF	0.8	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6.2	0.129	0.097	0.129	0.113	0.113	0.097	0.113	0.113	0.097
ME	0.6	0.5	0.9	0.8	0.8	0.8	0.8	0.8	0.8	6.8	0.088	0.074	0.132	0.118	0.118	0.118	0.118	0.118	0.118
STR	0.6	0.6	0.5	0.6	0.6	0.7	0.5	0.5	0.6	5.2	0.115	0.115	0.096	0.115	0.115	0.135	0.096	0.096	0.115
LTR	0.6	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6	0.1	0.1	0.133	0.117	0.117	0.1	0.117	0.117	0.1
LOP	0.6	0.6	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.8	0.103	0.103	0.138	0.103	0.103	0.103	0.121	0.121	0.103

e(pu21) 0.998 e(pu22) 0.997 e(pu23) 0.994 e(pu24) 1 e(pu25) 0.998 e(pu26) 0.998

General Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostatic
BGR	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.085	0.085	0.136	0.136	0.102
EHSE	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.085	0.085	0.136	0.136	0.102
ETFC	0.8	0.8	0.7	0.8	0.5	0.5	0.5	0.5	0.5	5.6	0.143	0.143	0.125	0.143	0.089	0.089	0.089	0.089	0.089

e(pu31) 0.989 e(pu32) 0.989 e(pu33) 0.989

Step4: E(First Env) 9.935 E(Second Env) 5.983 E(Third Env) 2.968

First Environment

F(u11)	0.153	F(U12)	0.153	F(U13)	0.148	F(U14)	0.08	F(U15)	0.047	F(U16)	0.015	F(U17)	0.118
F(U18)	0.037	F(U19)	0.022	F(U20)	0.227								

Second Environment

F(u21)	0.092	F(U22)	0.149	F(U23)	0.334	F(U24)	0.15	F(U25)	0.129	F(U26)	0.142

Third Environment

F(U31)	0.326	F(U32)	0.326	F(U33)	0.348

Step6:

w11	w12	w13	w14	w15	w16	w17	w18	w19	w10	w21	w22	w23	w24	w25	w26	w31	w32	w33
0.055	0.055	0.123	0.049	0.037	0.078	0.237	0.197	0.101	0.068	0.07	0.21	0.242	0.058	0.231	0.187	0.14	0.333	0.528

F'(U11)	0.089	F'(U12)	0.089	F'(U13)	0.192	F'(U14)	0.04	F'(U15)	0.018	F'(U16)	0.013	F'(U17)	0.294
F'(U18)	0.078	F'(U19)	0.023	F'(U20)	0.163	F'(U21)	0.04	F'(U22)	0.17	F'(U23)	0.44	F'(U24)	0.049
F'(U25)	0.162	F'(U26)	0.144	F'(U31)	0.135	F'(U32)	0.32	F'(U33)	0.544				

Step 7:

Risk Aversion Factor

First Env		Second Env		Third Env	
DCR	0.08	AID	0.2	BGR	0.2
DTR	0.08	AHDF	0.8	EHSE	0.6
UCR	0.8	ME	0.8	ETFC	0.8
MCR	0.08	STR	0.08		
CCR	0.08	LTR	0.8		
DE/DF	0.2	LOP	0.4		
IP	0.8				
QL	0.8				
PE	0.4				
IPR	0.2				

Step8:

First Env weight	Second Env weigl	Thrid Env weight
0.634	0.192	0.174

Laser wrt First Env		Laser wrt Second Env		Laser wrt Third Env	
U	0.468	U	0.106	U	0.112
		Risk Adjusted Opportunity Value for Laser	**0.686**		
EBW wrt First Env		EBW wrt 2nd Env		EBW wrt 3rd Env	
U	0.453	U	0.09	U	0.12
		Risk Adjusted Opportunity Value for EBW	**0.663**		
FSW wrt First Env		FSW wrt 2nd Env		FSW wrt 3rd Env	
U	0.331	U	0.148	U	0.127
		Risk Adjusted Opportunity Value for FSW	**0.606**		
Plasma wrt First Env		Plasma wrt 2nd Env		Plasma wrt 3rd Env	
U	0.328	U	0.124	U	0.104
		Risk Adjusted Opportunity Value for Plasma	**0.556**		
SMD wrt First Env		SMD wrt 2nd Env		SMD wrt 3rd Env	
U	0.462	U	0.125	U	0.073
		Risk Adjusted Opportunity Value for SMD	**0.66**		
DLD wrt First Env		DLD wrt 2nd Env		DLD wrt 3rd Env	
U	0.446	U	0.119	U	0.073
		Risk Adjusted Opportunity Value for DLD	**0.638**		
LFW wrt First Env		LFW wrt 2nd Env		LFW wrt 3rd Env	
U	0.355	U	0.127	U	0.098
		Risk Adjusted Opportunity Value for LFW	**0.58**		
RFW wrt First Env		RFW wrt 2nd Env		RFW wrt 3rd Env	
U	0.295	U	0.127	U	0.098
		Risk Adjusted Opportunity Value for RFW	**0.52**		
Isostatic wrt First Env		Isostatic wrt 2nd Env		Isostatic wrt 3rd Env	
U	0.434	U	0.118	U	0.081
		Risk Adjusted Opportunity Value for Isostatic	**0.633**		

Step 1: **(Opportunities)** **Engine Component No.6**

e(max) 2.197

Step 2:

K 0.455

Step3:

Manufacturing Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostat
DCR	0.8	0.9	0.7	0.6	0.8	0.7	0.7	0.6	0.9	6.7	0.119	0.134	0.104	0.09	0.119	0.104	0.104	0.09	0.134
DTR	0.6	0.6	0.6	0.8	0.7	0.7	0.6	0.5	0.6	5.7	0.105	0.105	0.105	0.14	0.123	0.123	0.105	0.088	0.105
UCR	0.7	0.9	0.9	0.5	0.8	0.6	0.7	0.6	0.6	6.3	0.111	0.143	0.143	0.079	0.127	0.095	0.111	0.095	0.095
MCR	0.7	0.8	0.5	0.6	0.6	0.7	0.7	0.7	0.5	5.8	0.121	0.138	0.086	0.103	0.103	0.121	0.121	0.121	0.086
CCR	0.5	0.5	0.5	0.5	0.7	0.5	0.5	0.5	0.5	4.7	0.106	0.106	0.106	0.106	0.149	0.106	0.106	0.106	0.106
DE/DF	0.6	0.6	0.6	0.6	0.7	0.7	0.6	0.6	0.6	5.6	0.107	0.107	0.107	0.107	0.125	0.125	0.107	0.107	0.107
IP	0.7	0.7	0.7	0.6	0.7	0.6	0.6	0.6	0.6	5.8	0.121	0.121	0.121	0.103	0.121	0.103	0.103	0.103	0.103
QL	0.6	0.7	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.9	0.102	0.119	0.136	0.102	0.102	0.102	0.119	0.119	0.102
PE	0.5	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6	5.4	0.093	0.111	0.13	0.111	0.111	0.111	0.111	0.111	0.111
IPR	0.5	0.5	0.2	0.5	0.6	0.6	0.5	0.5	0.6	4.5	0.111	0.111	0.044	0.111	0.133	0.133	0.111	0.111	0.133

e(pu11)	0.995	e(pu12)	0.996	e(pu13)	0.992	e(pu14)	0.995	e(pu15)	0.997	e(pu16)	0.999	e(pu17)	0.999
e(pu18)	0.998	e(pu19)	0.999	e(pu20)	0.985								

Supply Chain Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostat
AID	0.5	0.5	0.6	0.5	0.6	0.6	0.6	0.6	0.6	5.1	0.098	0.098	0.118	0.098	0.118	0.118	0.118	0.118	0.118
AHDF	0.8	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6.2	0.129	0.097	0.129	0.113	0.113	0.097	0.113	0.113	0.097
ME	0.6	0.5	0.9	0.8	0.8	0.8	0.8	0.8	0.8	6.8	0.088	0.074	0.132	0.118	0.118	0.118	0.118	0.118	0.118
STR	0.6	0.6	0.5	0.6	0.6	0.7	0.5	0.5	0.6	5.2	0.115	0.115	0.096	0.115	0.115	0.135	0.096	0.096	0.115
LTR	0.6	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6	0.1	0.1	0.133	0.117	0.117	0.1	0.117	0.117	0.1
LOP	0.6	0.6	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.8	0.103	0.103	0.138	0.103	0.103	0.103	0.121	0.121	0.103

e(pu21)	0.998	e(pu22)	0.997	e(pu23)	0.994	e(pu24)	0.997	e(pu25)	0.998	e(pu26)	0.998

General Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostat
BGR	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.085	0.085	0.136	0.136	0.102
EHSE	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.085	0.085	0.136	0.136	0.102
ETFC	0.8	0.8	0.7	0.8	0.5	0.5	0.5	0.5	0.5	5.6	0.143	0.143	0.125	0.143	0.089	0.089	0.089	0.089	0.089

e(pu31)	0.989	e(pu32)	0.989	e(pu33)	0.989

Step4: E(First Env) 9.954 E(Second Env) 5.983 E(Third Env) 2.968

Step5:

First Environment

F(U11)	0.102	F(U12)	0.082	F(U13)	0.18	F(U14)	0.112	F(U15)	0.066	F(U16)	0.022	F(U17)	0.03
F(U18)	0.053	F(U19)	0.031	F(U20)	0.322								

Second Environment

F(U21)	0.092	F(U22)	0.149	F(U23)	0.334	F(U24)	0.154	F(U25)	0.129	F(U26)	0.142

Third Environment

F(U31)	0.326	F(U32)	0.326	F(U33)	0.348

Step6:

w11	w12	w13	w14	w15	w16	w17	w18	w19	w10	w21
0.055	0.055	0.123	0.049	0.037	0.078	0.237	0.197	0.101	0.068	0.072

w22	w23	w24	w25	w26	w31	w32	w33
0.21	0.242	0.058	0.231	0.187	0.14	0.333	0.528

F'(U11)	0.067	F'(U12)	0.053	F'(U13)	0.262	F'(U14)	0.065	F'(U15)	0.029	F'(U16)	0.02	F'(U17)	0.083
F'(U18)	0.124	F'(U19)	0.037	F'(U20)	0.259	F'(U21)	0.036	F'(U22)	0.17	F'(U23)	0.44	F'(U24)	0.049
F'(U25)	0.162	F'(U26)	0.144	F'(U31)	0.135	F'(U32)	0.321	F'(U33)	0.544				

Step 7:

Risk Aversion Factor

First Env		Second Env		Third Env	
DCR	0.08	AID	0.2	BGR	0.2
DTR	0.08	AHDF	0.8	EHSE	0.6
UCR	0.8	ME	0.8	ETFC	0.8
MCR	0.08	STR	0.08		
CCR	0.08	LTR	0.8		
DE/DF	0.2	LOP	0.4		
IP	0.8				
QL	0.8				
PE	0.4				
IPR	0.2				

Step8:

First Env weight	Second Env weight	Thrid Env weight
0.634	0.192	0.174

Laser wrt First Env		Laser wrt Second Env		Laser wrt Third Env	
U	0.36	U	0.106	U	0.112
		Risk Adjusted Opportunity Value for Laser	**0.578**		
EBW wrt First Env		EBW wrt 2nd Env		EBW wrt 3rd Env	
U	0.42	U	0.09	U	0.12
		Risk Adjusted Opportunity Value for EBW	**0.63**		
FSW wrt First Env		FSW wrt 2nd Env		FSW wrt 3rd Env	
U	0.363	U	0.148	U	0.127
		Risk Adjusted Opportunity Value for FSW	**0.638**		
Plasma wrt First Env		Plasma wrt 2nd Env		Plasma wrt 3rd Env	
U	0.316	U	0.124	U	0.104
		Risk Adjusted Opportunity Value for Plasma	**0.544**		
SMD wrt First Env		SMD wrt 2nd Env		SMD wrt 3rd Env	
U	0.402	U	0.125	U	0.073
		Risk Adjusted Opportunity Value for SMD	**0.6**		
DLD wrt First Env		DLD wrt 2nd Env		DLD wrt 3rd Env	
U	0.356	U	0.119	U	0.073
		Risk Adjusted Opportunity Value for DLD	**0.548**		
LFW wrt First Env		LFW wrt 2nd Env		LFW wrt 3rd Env	
U	0.361	U	0.127	U	0.098
		Risk Adjusted Opportunity Value for LFW	**0.586**		
RFW wrt First Env		RFW wrt 2nd Env		RFW wrt 3rd Env	
U	0.335	U	0.127	U	0.098
		Risk Adjusted Opportunity Value for RFW	**0.56**		
Isostatic wrt First Env		Isostatic wrt 2nd Env		Isostatic wrt 3rd Env	
U	0.351	U	0.118	U	0.081
		Risk Adjusted Opportunity Value for Isostatic	**0.55**		

Step 1: **(Opportunities)** **Engine Component No.7**

e(max) 2.197

Step 2:

K 0.455

Step3:

Manufacturing Environment

Factor	Laser	EBW	FSW	Plasm	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati
DCR	0.9	0.9	0.7	0.6	0.9	0.8	0.7	0.6	0.9	7	0.129	0.129	0.1	0.086	0.129	0.114	0.1	0.086	0.129
DTR	0.7	0.7	0.6	0.8	0.8	0.8	0.6	0.5	0.7	6.2	0.113	0.113	0.097	0.129	0.129	0.129	0.097	0.081	0.113
UCR	0.8	0.9	0.9	0.5	0.9	0.7	0.7	0.6	0.7	6.7	0.119	0.134	0.134	0.075	0.134	0.104	0.104	0.09	0.104
MCR	0.7	0.8	0.5	0.6	0.6	0.7	0.7	0.7	0.5	5.8	0.121	0.138	0.086	0.103	0.103	0.121	0.121	0.121	0.086
CCR	0.5	0.5	0.5	0.5	0.7	0.5	0.5	0.5	0.5	4.7	0.106	0.106	0.106	0.106	0.149	0.106	0.106	0.106	0.106
DE/DF	0.6	0.6	0.6	0.6	0.7	0.7	0.6	0.6	0.6	5.6	0.107	0.107	0.107	0.107	0.125	0.125	0.107	0.107	0.107
IP	0.8	0.7	0.7	0.6	0.7	0.7	0.6	0.5	0.7	6	0.133	0.117	0.117	0.1	0.117	0.117	0.1	0.083	0.117
QL	0.6	0.7	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.9	0.102	0.119	0.136	0.102	0.102	0.102	0.119	0.119	0.102
PE	0.5	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6	5.4	0.093	0.111	0.13	0.111	0.111	0.111	0.111	0.111	0.111
IPR	0.5	0.5	0.2	0.5	0.6	0.6	0.5	0.5	0.6	4.5	0.111	0.111	0.044	0.111	0.133	0.133	0.111	0.111	0.133
e(pu11)	0.994		e(pu12)	0.995		e(pu13)	0.992		e(pu14)	0.995		e(pu15)	0.997		e(pu16)	0.999		e(pu17)	0.996
e(pu18)	0.998		e(pu19)	0.999		e(pu20)	0.985												

Supply Chain Environment

Factor	Laser	EBW	FSW	Plasm	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati
AID	0.5	0.5	0.6	0.5	0.6	0.6	0.6	0.6	0.6	5.1	0.098	0.098	0.118	0.098	0.118	0.118	0.118	0.118	0.118
AHDF	0.8	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6.2	0.129	0.097	0.129	0.113	0.113	0.097	0.113	0.113	0.097
ME	0.6	0.5	0.9	0.8	0.8	0.8	0.8	0.8	0.8	6.8	0.088	0.074	0.132	0.118	0.118	0.118	0.118	0.118	0.118
STR	0.6	0.6	0.5	0.6	0.6	0.7	0.5	0.5	0.6	5.2	0.115	0.115	0.096	0.115	0.115	0.135	0.096	0.096	0.115
LTR	0.6	0.6	0.8	0.7	0.7	0.6	0.7	0.7	0.6	6	0.1	0.1	0.133	0.117	0.117	0.1	0.117	0.117	0.1
LOP	0.6	0.6	0.8	0.6	0.6	0.6	0.7	0.7	0.6	5.8	0.103	0.103	0.138	0.103	0.103	0.103	0.121	0.121	0.103
e(pu21)	0.998		e(pu22)	0.997		e(pu23)	0.994		e(pu24)	0.997		e(pu25)	0.998		e(pu26)	0.998			

General Environment

Factor	Laser	EBW	FSW	Plasm	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati
BGR	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.085	0.085	0.136	0.136	0.102
EHSE	0.6	0.7	0.9	0.5	0.5	0.5	0.8	0.8	0.6	5.9	0.102	0.119	0.153	0.085	0.085	0.085	0.136	0.136	0.102
ETFC	0.8	0.8	0.7	0.8	0.5	0.5	0.5	0.5	0.5	5.6	0.143	0.143	0.125	0.143	0.089	0.089	0.089	0.089	0.089
e(pu31)	0.989		e(pu32)	0.989		e(pu33)	0.989												

Step4: E(First Env) 9.951 E(Second Env 5.983 E(Third Env) 2.968

Step5:

First Environment

F(U11)	0.117	F(U12)	0.099	F(U13)	0.154	F(U14)	0.103	F(U15)	0.061	F(U16)	0.02	F(U17)	0.071
F(U18)	0.049	F(U19)	0.029	F(U20)	0.297								

Second Environment

F(U21)	0.092	F(U22)	0.149	F(U23)	0.334	F(U24)	0.154	F(U25)	0.129	F(U26)	0.142

Third Environment

F(U31)	0.326	F(U32)	0.326	F(U33)	0.348

Step6:

w11	w12	w13	w14	w15	w16	w17	w18	w19	w10	w21	w22	w23	w24	w25	w26	w31	w32	w33
0.055	0.055	0.123	0.049	0.037	0.078	0.237	0.197	0.101	0.068	0.072	0.21	0.242	0.058	0.231	0.187	0.14	0.333	0.528

F'(U11)	0.072	F'(U12)	0.061	F'(U13)	0.212	F'(U14)	0.057	F'(U15)	0.025	F'(U16)	0.017	F'(U17)	0.189
F'(U18)	0.108	F'(U19)	0.032	F'(U20)	0.226	F'(U21)	0.036	F'(U22)	0.17	F'(U23)	0.44	F'(U24)	0.049
F'(U25)	0.162	F'(U26)	0.144	F'(U31)	0.135	F'(U32)	0.321	F'(U33)	0.544				

Step 7:

Risk Aversion Factor

First Env		Second Env		Third Env	
DCR	0.08	AID	0.2	BGR	0.2
DTR	0.08	AHDF	0.8	EHSE	0.6
UCR	0.8	ME	0.8	ETFC	0.8
MCR	0.08	STR	0.08		
CCR	0.08	LTR	0.8		
DE/DF	0.2	LOP	0.4		
IP	0.8				
QL	0.8				
PE	0.4				
IPR	0.2				

Step8:

First Env weight	Second Env weigl	Thrid Env weight
0.634	0.192	0.174

Laser wrt First Env		Laser wrt Second Env			Laser wrt Third Env	
U	0.403	U	0.106		U	0.112
		Risk Adjusted Opportunity Value for Laser		**0.62**		
EBW wrt First Env		EBW wrt 2nd Env			EBW wrt 3rd Env	
U	0.42	U	0.09		U	0.12
		Risk Adjusted Opportunity Value for EBW		**0.63**		
FSW wrt First Env		FSW wrt 2nd Env			FSW wrt 3rd Env	
U	0.364	U	0.148		U	0.127
		Risk Adjusted Opportunity Value for FSW		**0.639**		
Plasma wrt First Env		Plasma wrt 2nd Env			Plasma wrt 3rd Env	
U	0.321	U	0.124		U	0.104
		Risk Adjusted Opportunity Value for Plasma		**0.549**		
SMD wrt First Env		SMD wrt 2nd Env			SMD wrt 3rd Env	
U	0.428	U	0.125		U	0.073
		Risk Adjusted Opportunity Value for SMD		**0.626**		
DLD wrt First Env		DLD wrt 2nd Env			DLD wrt 3rd Env	
U	0.39	U	0.119		U	0.073
		Risk Adjusted Opportunity Value for DLD		**0.582**		
LFW wrt First Env		LFW wrt 2nd Env			LFW wrt 3rd Env	
U	0.357	U	0.127		U	0.098
		Risk Adjusted Opportunity Value for LFW		**0.582**		
RFW wrt First Env		RFW wrt 2nd Env			RFW wrt 3rd Env	
U	0.322	U	0.127		U	0.098
		Risk Adjusted Opportunity Value for RFW		**0.547**		
Isostatic wrt First Env		Isostatic wrt 2nd Env			Isostatic wrt 3rd Env	
U	0.382	U	0.118		U	0.081
		Risk Adjusted Opportunity Value for Isostatic		**0.581**		

Step 1: **(Standard Threat Calculation for All Engine Components)**

e(max) 2.197

Step 2:

K 0.455

Step3:

Manufacturing Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati
CC	0.2	0.1	0.3	0.1	0.2	0.3	0.3	0.3	0.4	2.2	0.091	0.045	0.136	0.045	0.091	0.136	0.136	0.136	0.182
SRC	0.2	0.2	0.4	0.2	0.3	0.3	0.2	0.2	0.3	2.3	0.087	0.087	0.174	0.087	0.13	0.13	0.087	0.087	0.13
TE	0.3	0.3	0.1	0.2	0.3	0.3	0.2	0.2	0.4	2.3	0.13	0.13	0.043	0.087	0.13	0.13	0.087	0.087	0.174
SI	0.4	0.2	0.4	0.3	0.2	0.2	0.3	0.3	0.2	2.5	0.16	0.08	0.16	0.12	0.08	0.08	0.12	0.12	0.08
TM	0.2	0.4	0.1	0.4	0.3	0.2	0.3	0.3	0.2	2.4	0.083	0.167	0.042	0.167	0.125	0.083	0.125	0.125	0.083
PNE/RL	0.3	0.1	0.3	0.1	0.1	0.3	0.1	0.1	0.5	1.9	0.158	0.053	0.158	0.053	0.053	0.158	0.053	0.053	0.263
MCR	0.3	0.3	0.5	0.1	0.1	0.2	0.2	0.2	0.4	2.3	0.13	0.13	0.217	0.043	0.043	0.087	0.087	0.087	0.174
e(pu11)	0.962		e(pu12)	0.984		e(pu13)	0.974		e(pu14)	0.982		e(pu15)	0.97		e(pu16)	0.91		e(pu17)	0.945

Supply Chain Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati
IAT	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.1	1.1	0.091	0.091	0.273	0.091	0.091	0.091	0.091	0.091	0.091
TA	0.3	0.2	0.2	0.4	0.1	0.1	0.2	0.2	0.1	1.8	0.167	0.111	0.111	0.222	0.056	0.056	0.111	0.111	0.056
KBO	0.2	0.3	0.1	0.3	0.1	0.1	0.2	0.3	0.1	1.7	0.118	0.176	0.059	0.176	0.059	0.059	0.118	0.176	0.059
CI	0.2	0.1	0.4	0.1	0.3	0.3	0.3	0.4	0.1	2.2	0.091	0.045	0.182	0.045	0.136	0.136	0.136	0.182	0.045
FC	0.3	0.4	0.1	0.1	0.2	0.3	0.3	0.3	0.5	2.5	0.12	0.16	0.04	0.04	0.08	0.12	0.12	0.12	0.2
TS	0.1	0.2	0.4	0.1	0.3	0.3	0.3	0.4	0.3	2.4	0.042	0.083	0.167	0.042	0.125	0.125	0.125	0.167	0.125
e(pu21)	0.955		e(pu22)	0.952		e(pu23)	0.951		e(pu24)	0.944		e(pu25)	0.952		e(pu26)	0.96			

General Environment

Factor	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati	SUM	Laser	EBW	FSW	Plasma	SMD	DLD	LFW	RFW	Isostati
LCA	0.3	0.3	0.2	0.3	0.3	0.2	0.2	0.2	0.2	2.2	0.136	0.136	0.091	0.136	0.136	0.091	0.091	0.091	0.091
ROI	0.2	0.2	0.5	0.1	0.3	0.3	0.2	0.3	0.1	2.2	0.091	0.091	0.227	0.045	0.136	0.136	0.091	0.136	0.045
CGR	0.3	0.2	0.1	0.3	0.3	0.2	0.2	0.2	0.1	1.9	0.158	0.105	0.053	0.158	0.158	0.105	0.105	0.105	0.053
TU	0.3	0.1	0.5	0.1	0.3	0.4	0.3	0.3	0.4	2.7	0.111	0.037	0.185	0.037	0.111	0.148	0.111	0.111	0.148
e(pu31)	0.991		e(pu32)	0.95		e(pu33)	0.97		e(pu34)	0.955									

Step4: E(First Env) 6.728 E(Second Env) 5.713 E(Third Env) 3.866

Step5:

First Environment

F(U11)	0.14	F(U12)	0.057	F(U13)	0.095	F(U14)	0.066	F(U15)	0.111	F(U16)	0.329	F(U17)	0.201

Second Environment

F(U21)	0.157	F(U22)	0.168	F(U23)	0.173	F(U24)	0.195	F(U25)	0.166	F(U26)	0.14

Third Environment

F(U31)	0.07	F(U32)	0.375	F(U33)	0.221	F(U34)	0.334

Step6:

w11	w12	w13	w14	w15	w16	w17	w21	w22	w23	w24	w25	w26	w31	w32	w33	w34
0.206	0.103	0.042	0.087	0.149	0.136	0.277	0.088	0.204	0.079	0.055	0.449	0.125	0.477	0.275	0.095	0.153

F'(U11)	0.178	F'(U12)	0.036	F'(U13)	0.025	F'(U14)	0.035	F'(U15)	0.103	F'(U16)	0.277	F'(U17)	0.345
F'(U21)	0.084	F'(U22)	0.208	F'(U23)	0.083	F'(U24)	0.065	F'(U25)	0.453	F'(U26)	0.106	F'(U31)	0.159
F'(U32)	0.495	F'(U33)	0.101	F'(U34)	0.245								

Step 7:

Risk Aversion Factor

First Env		Second Env		Third Env	
CC	0.8	IAT	0.08	LCA	0.8
SRC	0.2	TA	0.8	ROI	0.8
TE	0.08	KBO	0.08	CGR	0.06
SI	0.08	CI	0.08	TU	0.6
TM	0.4	FC	0.8		
PNE/RL	0.4	TS	0.2		
MCR	0.8				

Step8:

First Env weight	Second Env we	Thrid Env weight
0.634	0.192	0.174

Laser wrt First Env	Laser wrt Second Env		Laser wrt Third Env
T -0.211	T -0.06		T -0.06
	Risk Adjusted Threat Value for Laser	**-0.331**	
EBW wrt First Env	EBW wrt 2nd Env		EBW wrt 3rd Env
T -0.167	T -0.067		T -0.04
	Risk Adjusted Threat Value for EBW	**-0.274**	
FSW wrt First Env	FSW wrt 2nd Env		FSW wrt 3rd Env
T -0.264	T -0.044		T -0.09
	Risk Adjusted Threat Value for FSW	**-0.398**	
Plasma wrt First Env	Plasma wrt 2nd Env		Plasma wrt 3rd Env
T -0.113	T -0.043		T -0.03
	Risk Adjusted Threat Value for Plasma	**-0.186**	
SMD wrt First Env	SMD wrt 2nd Env		SMD wrt 3rd Env
T -0.123	T -0.043		T -0.07
	Risk Adjusted Threat Value for SMD	**-0.236**	
DLD wrt First Env	DLD wrt 2nd Env		DLD wrt 3rd Env
T -0.197	T -0.054		T -0.07
	Risk Adjusted Threat Value for DLD	**-0.321**	
LFW wrt First Env	LFW wrt 2nd Env		LFW wrt 3rd Env
T -0.163	T -0.06		T -0.05
	Risk Adjusted Threat Value for LFW	**-0.273**	
RFW wrt First Env	RFW wrt 2nd Env		RFW wrt 3rd Env
T -0.163	T -0.065		T -0.06
	Risk Adjusted Threat Value for RFW	**-0.288**	
Isostatic wrt First Env	Isostatic wrt 2nd Env		Isostatic wrt 3rd Env
T -0.296	T -0.069		T -0.04
	Risk Adjusted Threat Value for Isostatic	**-0.405**	

Appendix I

Risk Aversion Factor Calculations

The risk aversion factor in strategic assessment model (SAM) is calculated by equating utility of certainty equivalence (C.E) and utility of an exponential function.

Utility of Certainty Equivalence = u (C.E) = 0.5 u (1) +0.5 u (0)........ (1)

Utility of an Exponential Function = $u = 1/r\ (1- e^{-rp})$......... (2)

Equating equation (1) and (2) putting p =C.E

$$1/r\ (1- e^{-rp}) = 0.5[1/r\ (1- e^{-r})] +0$$

$$e^{-rp} - 0.5\, e^{-r} = 0.5 \quad \ldots\ldots\ldots (3)$$

The technology managers were asked the possibility of occurrence and possibility of non occurrence of an opportunity and threat as shown in equation (1). Where 1 represents occurrence and 0 represents non occurrence of an opportunity or threats. So the expected value of lottery in equation (1) is 0.50 and the technology managers were asked to provide a C.E value between 0 and 0.50 where 0 represented complete risk aversion and 0.50 represented complete risk neutrality. Using equation (3) the corresponding value of risk aversion factor was then determined.