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The Management of Manufacturing Trade-offs

by

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LIST OF ABBREVIATIONS

MS .... MANUFACTURING STRATEGY
MSD .... MANUFACTURING STRATEGY DIMENSION
OM .... OPERATIONS MANAGEMENT
QC .... A QUALITY VERSUS COST TRADE-OFF
.... OTHER INITIALS REFER TO VARIETY (V), SPEED (S) AND DEPENDABILITY (D)
WCM .... WORLD CLASS MANUFACTURING

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SUMMARY

This thesis investigates the nature and management of manufacturing trade-offs. It examines the properties and features of trade-offs in the context of manufacturing systems and the ways that operations management may deal with them.

The need for such an investigation stems from (a) the increasing interest in trade-offs, (b) the implicit use of trade-offs in many recent popular operations literature, (c) the interest in the dynamic competencies literature and (d) the apparent lack of trade-offs methods or an overall framework. This study reflects the need to extend the trade-offs research from its present descriptive focus to an explanatory and hopefully more elucidating focus.

This research is based on a number of case studies of manufacturing companies in Great Britain and Brazil. Data concerning their trade-offs were collected mainly through the examination of documents, observations of shop-floor activities and interviews with the systems' key operations managers. Following analysis identified the major data within and across the cases about the properties, features and management of trade-offs.

This investigation suggests mainly that trade-offs between MSDs do exist; that their structure can be visualised as base, pivot and function; that they are contingent and dynamic; that their performance is different from their importance; that these depend on a range of external and internal factors; that one can improve trade-offs through alternative strategies and that flexibility may have a pivotal role in this process.

The major original contributions of this explanatory, in-depth investigation are (a) the development of a trade-offs model that may be more accurate and useful than previous models in the literature; (b) the distinction between the performance and importance of trade-offs; (c) the taxonomy of trade-offs management strategies and (d) the identification of the role of flexibility in trade-offs management, with emphasis on the distinction between the ideas of flexibility and variety in that context.

Introduction

So the basic notion of trade-offs turns away some academics and managers. This is a fact whether or not we perceive the criticism as reasonable or simplistic. The fix is not to stop using the idea. The fix could be just to drop the word and substitute 'performance relationships' or something better. But what is really needed is research to develop more knowledge and the specifics of these constraints.

Wickham Skinner (1992: 21)

I Background

The concept of manufacturing trade-offs is arguably one of the paradigms of operations management whose importance has increased most during the last years. Manufacturing strategy studies have long been discussing the nature and role of the appropriately named Manufacturing Strategy Dimensions in operations management. Assumptions on the existence and nature of trade-offs between MSDs are among the major characteristics that distinguish upon these different studies.

Studies in the 70's defined the idea of trade-offs in manufacturing strategy. They realised that operations systems could no longer compete only in a cost productivity basis but rather along multiple dimensions (Skinner, 1969; Banks and Wheelright, 1979). Those studies viewed trade-offs as a marked characteristic of that new context; an undesired yet natural attribute of a new industrial scenario. Hence they investigated the ways by which operations management should recognise and adapt to trade-offs (Skinner, 1974; Hayes and Schmenner, 1978; Miller, 1983).

Those ideas were disputed in the 80's by studies suggesting that some companies seemed able to defy the idea of trade-offs. These firms seemed to outperform their competitors in many areas simultaneously. Such competitive power was enabling then to win markets all around the world. Hence their modus operandi was called 'World Class Manufacturing' (Schonberger, 1986; Collins and Schmenner, 1993). The WCM theory thus challenged the idea of trade-offs between MSDs: if trade-offs exist, how do such companies excel in all those areas? These studies regarded manufacturing trade-offs a myth and urged operations managers to pursue all their goals in concert.

However, empirical studies in fields such as operations management, industrial economics or production engineering would not corroborate WCM ideas. Operations systems have still limited resources and can not simply achieve everything. On the other hand, the cases presented by WCM studies pointed out a reality that the earlier theory could not explain either. It was necessary to elucidate how some firms could exceed in many areas despite not getting clear of trade-offs. Further studies were needed to suggest ideas that might solve this paradox (Skinner, 1992; New, 1992).

Such new studies have been proposing that trade-offs still exist but they are dynamic (Skinner, 1992; Hayes and Pisano, 1994). Operations management has to recognise and improve continually the resources and capabilities available in the system to redefine the nature of trade-offs (Slack et al., 1995). Trade-offs exist but their performance and importance are contingent to environment variables that may be improved (New, 1992; Filippini, Forza and Vinelly, 1995).

As part of that effort to understand such reality, this study develops some ideas that may extend the knowledge about the nature, sources, effects and management of trade-offs in the context of manufacturing. To achieve that, the research brings the existing knowledge on manufacturing strategy, flexibility and trade-offs together with case studies of manufacturing companies to build a framework of trade-offs.

II Justification

The need for further research on manufacturing trade-offs was pointed out by authors such as Skinner (1992), New (1992) and Schroeder et al. (1996). This stems from at least three major factors:

1. Industrial markets' competition has moved from a focus on single dimensions (specially cost productivity and quality) to a focus on multiple dimensions (Filippini, Forza and Vinelli, 1995; Hayes and Pisano, 1994). Today's successful firms need to deal with trade-offs to be able to achieve superior performance in many areas. Hence there is a need to define frameworks that may help operations management to deal successfully with trade-offs;
2. The operations management literature has so far provided little knowledge on the nature, sources, effects and management of trade-offs. Recent studies focus still on a debate on whether they exist or not (Mapes, 1996; Schroeder et al., 1996). Some studies focused on the sources (Filippini, Forza and Vinelli, 1995; Ferdows and De Meyer, 1990) or nature (Skinner, 1992; Hayes and Pisano, 1995) of trade-offs but only as separate from any general framework. Slack et al. (1995) defined the idea of trade-off pivot but did not suggest what this is in practice;
3. The few ideas suggesting how operations management can deal with trade-offs in practice seem to be simplistic and/or lack empirical evidence. The World Class Manufacturing theory of Schonberger (1986) has been criticised for its lack of research evidence and simplistic view of operations management (New, 1992; Skinner, 1992). Ferdows and De Meyer's (1990) Sand Cone Model was not corroborated by Wood (1991) and just partially corroborated by Noble (1995).

These factors are obviously related. The problem is that trade-offs have got an increasing role in the new context of manufacturing that is still not well understood. It seems difficult to define reliable approaches to deal with trade-offs in this new context before one really understands what are their sources, effects and nature. Extending such knowledge is the major objective of this study.

III Research Structure

This study is divided into four parts (see Figure 0-1). Part I is the literature review. It discusses the relevant literature that grounds the investigation. Chapter 1 is about manufacturing strategy, Chapter 2 is about manufacturing flexibility and Chapter 3 is about manufacturing trade-offs. This literature unveils the major ideas to ground the choice of the research methodology in Part II.

Part II concerns the definition of the methodological aspects of this research. This is based on ideas from the literature review in Part I and on theoretical studies on research methods in Social Sciences. Chapter 4 defines the research framework, objectives and propositions. Chapter 5 discusses the major aspects of the research methods such as research strategies, research paradigms and the process of data collection and analysis. Chapter 6 discusses the research design. The research design, methods and framework guide the process of data collection and analysis.

Part III presents the data analysis. Chapter 7 covers the within-case analysis of data. Each within-case analysis is a case study. Chapter 8 presents the cross-case comparison of those data. It stresses their major similarities and differences to ground the research results and conclusions following discussed.

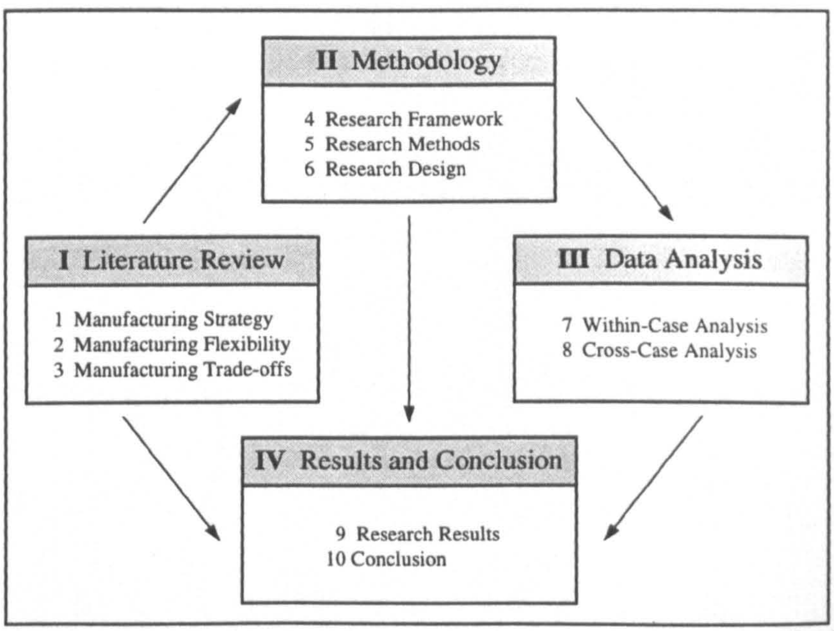

Figure 0-1: The structure of this research study

Finally, Part IV discusses the results and conclusions of this research. It combines the research data (Part III) with its framework (Part II) and literature (Part I) to develop a framework of trade-offs in the context of manufacturing. Chapter 9 discusses the research findings that constitute this framework. It covers the concept, nature, sources, effects and management of trade-offs and the role of flexibility in that. Chapter 10 is the study's conclusions. It summarises the major research findings, discusses their implications and suggests some aspects that could be addressed in following studies.

Part I - Literature Review

Part I reviews the literature that is relevant to this research. It discusses the major ideas on manufacturing strategy, flexibility and trade-offs to be used along the research framework. Part I is divided into three chapters:

Chapter 1

Manufacturing Strategy

Chapter 2

Manufacturing Flexibility

Chapter 3

Manufacturing Trade-offs

Chapter 1 - Manufacturing Strategy

Chapter 1

Manufacturing Strategy

Introduction

The research on manufacturing strategy (MS) started in 1969 with Skinner's study on the competitive failures of USA industrial companies. According to Abernathy, Clark and Kantrow (1981), major industries such as textiles, machinery, computers and specially cars had not been able in that time to cope with the competitive changes imposed by new entrants, specially those from Japan. Industrial managers blamed factors such as government's regulations, trade-unions and the 1973's oil shock as their major competitive barriers. However, according to Hayes and Wheelright (1984), such problems had affected other nations too and could not justify competitive weaknesses that had started even before.

According to studies such as Skinner (1969; 1974), Hill (1985) and Hayes and Wheelright (1984), the major competitive obstacles came from inside those firms. Deficiencies ranging from strategic to operational mis-management were the real causes for the US and Europe's 'industrial decline'. The major factors stressed in these studies may be summarised in five points:

1. An emphasis on productivity and cost reduction at the expense of long term investments such as product and process innovation and research and development. This emphasis also reflected in a focusing on existing markets at the expense of new ones (Hayes and Wheelright, 1984; Skinner, 1969; 1974; Banks and Wheelright, 1979; Abernathy, Clark and Kantrow, 1981; Hill, 1985);
2. An excessive attention to finances and marketing at the expense of manufacturing and technology management. Manufacturing was considered a 'technical liability' instead of a competitive asset (Hayes and Wheelright, 1984; Skinner, 1969; Hill, 1985);

3. An excessive simplification in organisational design and a lack of integration between units. Manufacturing decisions usually concerned single areas and followed a marketing or finances point of view (Hayes and Wheelright, 1984);
4. The inappropriate application of financial portfolio theories to production assets. Production assets do not behave as financial assets. This led to excessive industrial diversification and a lack of focus on production performance (Abernathy, Clark and Kantrow, 1981). Companies would pay more attention to opportunities on mergers than to their markets (Hayes and Wheelright, 1984; Skinner, 1969; 1974);
5. The core competition factors were not related to manufacturing abilities. Manufacturing had no competitive role or coherence. Skinner (1969) called this 'the missing link' in production management (Hill, 1985; Hayes and Wheelright, 1984).

In the view of these authors, these factors related to the inability of strategic management to take manufacturing for a source of competitive advantage. While finances and marketing are supportive areas, manufacturing and sales are the main businesses. The answer for competitive problems relied in the co-ordination between strategy and manufacturing. It was necessary to develop and apply a MS theory.

This chapter reviews the major ideas on MS starting from those early studies. Section 1.1 discusses the major MS concepts and frameworks. Sections 1.2 and 1.3 discuss the MS process and content. This is the application of those frameworks into practice. Section 1.4 discusses the recent literature on production resources and capabilities.

1.1 Manufacturing Strategy Concepts

The first step in the development of the MS theory was the definition of concepts and methods that could translate into practice the ideas from early studies. MS relies on core assumptions such as the compatibility between manufacturing and competitive strategy, the proactive role of manufacturing and the need for setting competitive priorities. These assumptions have been translated into operational concepts such as focused factories, qualifying and order winning criteria and the product-process matrix.

This section discusses the major MS concepts and methods. These ideas appeared from the beginning of the 70's and are increasingly important in both research and practice.

1.1.1 Focused Manufacturing

The idea of focused manufacturing was developed by Skinner (1974) and follows three major concerns. First, cost is not the only competitive yardstick. Cost used to be the primary performance objective of industrial firms in the 70's. However, competitive advantage may rely on other dimensions such as quality and speed. Second, a production system cannot perform well on every yardstick. OM should give priority to the objectives that best relate to the corporate strategy. Third, "simplicity and repetition breed competence" (1974: 115). The competitive advantage in manufacturing relies on a limited range of performance objectives that are compatible with the competitive strategy.

In 1974, when just-in-time and flexible manufacturing were still new ideas, Skinner tried to solve such conflicts through specialisation. He extended the idea of task specialisation, traditional in mass production, to the limits of the factory. Factories should focus on a limited range of objectives, products and tasks. They should concentrate on the most important competitive measures and keep the other measures in the limit necessary to support the main ones. According to Skinner, "a factory that focuses on a narrow product mix for a particular niche will outperform the conventional plant, which attempts a broader mission" (1974: 114). The division of bigger plants into smaller units could be achieved with the following methodology:

1. Developing an explicit, brief statement of corporate objectives and strategy;
2. Translating this statement into manufacturing language and meaning;
3. Making a careful examination of the elements of the production system and
4. Reorganising these elements to produce a consistent focus.

One major decision of the implementation of focused factories is the choice of the criteria to divide the units into groups (Hayes and Schmenner, 1978). The literature provides some different criteria, each one relating to different contexts (Table 1-1).

Criteria	Hayes and Wheelright (1984)	Hill (1985)	Lee (1990)	Sheu and Krajewski (1990)
Product	X	X	X	X
Process	X	X	X	X
OW Criteria[1]				X
Volume	X		X	
Market			X	
Geography			X	
Infrastructure			X	

Table 1-1: Criteria for factory focusing

Product and process are the most important among these criteria (Hayes and Schmenner, 1978). The facilities of a factory focused by product are designed to meet the needs of specific groups of products (Hill, 1983). This usually requires duplicating resources across facilities (Sheu and Krajewski, 1990). The facilities of a factory focused by process are divided according to their tasks (Hayes and Schmenner, 1978). According to Lee (1990), process plants are more difficult to co-ordinate and control than product plants.

There is a debate in the literature on whether focused factories are appropriate in the present context. Gerwin (1993) pointed out that the duplication of facilities to attend different focused plants leads to inefficient use of resources and excessive capacity levels. He also says that focused firms tend to be less responsive to changing markets. Hayes and Pisano (1994) suggested that flexible technologies are a better alternative than focused factories. Focused factories are inherently inflexible and have low scale economies that are not always compensated by scope economies. According to Wathen (1995: 11), "... the degree to which a business unit focuses on the operations and control of production process does not directly relate to higher performance". That means the implementation of focused factories has to follow other measures to guarantee superior performance.

On the other hand, focused factories have benefits such as lower system's complexity and improved control. Focused factories motivate workforce involvement and team-working

[1] Order-winning criteria - See Section 1.1.4.

practices. Since they deal with marketing niches, the environment control is easier and forecasts tend to be more accurate (Collins and Schmenner, 1993). The consistency within and between manufacturing attributes and marketing requirements increases (Bozarth, 1993). Focused factories may also minimise the impact of manufacturing trade-offs since different units focus on different objectives.

Thus, the value of focused factories depends on contingent aspects such as the system's environment, objectives and structure. They may concern only parts of the system and may serve as short-term basis for more comprehensive, long-term solutions. It is the role of OM to define whether they are appropriate and what benefits their implementation may bring.

1.1.2 The 4 Stages of Manufacturing Strategic Role

The failure of manufacturing to support the competitive strategy was originally one of the major concerns of MS. OM was restricted to *adapt* manufacturing to environment changes, usually after their occurrence. However, such approach is no longer compatible with the competitive practices. Manufacturing should have a proactive role in creating strategic opportunities and in supporting the competitive strategy. Naturally, turning 'reactive' systems into such proactive assets takes a long time. It requires persisting and progressive improvements in the manufacturing structure and culture (Wheelright and Hayes, 1985).

According to Wheelright and Hayes (1985), turning manufacturing into a competitive weapon should take four stages. Each stage concerns a more supportive and proactive role of manufacturing. Progressing through stages requires the development of superior capabilities and the strengthening of links between manufacturing and other areas. This development follows three major rules:

1. The stages are not mutually exclusive. Different areas may be in different stages. Improving poorest areas will probably have the major effect in the overall performance;
2. It is almost impossible to skip a stage;
3. Strengthening manufacturing requires not only desire but commitment and effort.

The first stage corresponds to an 'internally neutral' state. Manufacturing is unable to influence the competitive strategy. OM's major objective is to minimise the impact of manufacturing failures in other areas. Manufacturing management tends to be simple, avoiding aspects such as reliability and integration and focusing on cost productivity.

The second stage is the 'externally neutral' manufacturing. The production system should be as good as its major competitors'. This neutrality relies on copying industry practices and technologies. OM tends to avoid discontinuous changes and focus on investments in automation and scale economies.

Stage 3 concerns systems that actively support the competitive strategy (these are called 'internally supportive' systems). That is manufacturing decisions are consistent with the strategy. This is the first stage where the formulation of a MS is a reality. OM should influence and preferably take part in the competitive strategy formulation. Hum and Leow's (1996) empirical study suggested that most companies were between stages 2 and 3.

Finally, systems in stage 4 are 'externally supportive'. That is they are able to follow and contribute to the competitive strategy. Companies in this stage promote an intensive interaction between manufacturing and other functions, the seeking of expertise in new technologies and the continuous improvement of their structure and infrastructure.

The passage from stage 3 to 4 is the most beneficial but also the most difficult. It requires extensive restructuring of the manufacturing function and firm commitment. Factors such as in-house product development, attention to the manufacturing infrastructure and integration between product and process design are crucial to the 'big jump' to stage 4.

Taxonomies of manufacturing strategies - Sweeney (1991) proposed an alternative approach to Wheelright and Hayes'. He suggested that Wheelright and Hayes's approach is too prescriptive and that the link between manufacturing and corporate strategy could be 'progressively developed' through a taxonomy of manufacturing strategies.

He was not the first to develop such idea. Stobaugh and Telesio (1983) proposed a contingent model of three manufacturing strategies (technology-driven, marketing-intensive and low cost). Roth and Miller (1992) also defined a model of three strategies (caretakers, marketeers and innovators).

Sweeney (1991) suggested a taxonomy with four generic manufacturing strategies: caretaker, marketeer, reorganiser and innovator. Each strategy corresponds to a combination of Porter's (1985) competitive strategies with types of manufacturing process design (high volume and high variety). Each strategy concerns alternative types of manufacturing objectives, capabilities and resources. Sweeney, as Wheelright and Hayes, suggested that some strategies were better than others. In this case, however, the value of the strategies is also contingent to some environmental characteristics.

In a later study, Sweeney (1993) proposed that the firm should develop manufacturing through these strategies until reaching the 'longer-term vision' of innovator strategies. This development requires extensive changes in the supply chain, process and infrastructure.

1.1.3 The Product-Process Matrix

According to Spencer and Cox (1995), the linking between process strategies and product strategies has been suggested for a long time. By the end of the 70's, the emergence of new process management ideas such as group technology and focused factories demanded more than ever the understanding of that relationship.

The idea of a process life cycle follows that of a product life cycle. It suggests that typical production systems progress from an initially flexible and disconnected structure (a job shop system) to a mechanised and standardised (flow shop) structure. According to Hayes and Wheelright (1979a), this progress should be consistent with the variety and volume of products made in that system. That means process types should match corresponding product volume and range types. The set of combinations of process and product types is determined in a 'product-process matrix'.

The product-process matrix has two dimensions that are the product variety/volume dimension and the process type dimension. The product dimension has four levels that are low volume/low standardisation, low volume/multiple products, higher volume/few major products and high volume/high standardisation. Their corresponding levels in the process dimension are job shop, batch line, assembly line and continuous flow types. The product and process types should match in the main diagonal of the matrix. That is high product varieties correspond to highly flexible structures and so on. Systems matching in non-diagonal yardsticks are non-economical and have low competitiveness.

The matrix also indicates the performance objectives that should correspond to each product/process strategy. Flexibility and quality correspond to job shop and low volume structures. Cost and dependability correspond to continuous, high volume structures.

If new products have different volume and variety structures, they should be processed in corresponding new process structures, with specific layout, facilities, control systems and competitive strategies. This combines with the idea of focused manufacturing.

According to Hayes and Wheelright (1979b), OM has to continuously adapt the process and product structures as the firm grows. Changing the product or process structure with no corresponding change in the other dimension may lead to failures such as loosing focus. Furthermore, changes leading to an *addition* instead of *modification* in the other dimension may lead to failures such as de-focusing, over-capacity and high production costs.

Spencer and Cox (1995) revised Hayes and Wheelright ideas, trying to adapt these to a new context of just-in-time, cellular manufacturing and flexible systems. They suggested that the 'process structure' of Hayes and Wheelright should be better defined with "... the management of the resources rather than in terms of the technology or production planning and control system employed" (Spencer and Cox, 1995: 1289). That is the percentage of capacity allotted to a product line should determine its position in the matrix. This resolves apparent contradictions in the original method such as 'JIT strategies may have success in process systems' (Schonberger, 1983). Spencer and Cox's major finding is that the use of specific technology and PPC systems types is not precluded by the process structure. Different types may be successfully applied to either low or high volume systems.

1.1.4 Qualifying and Order-Winning Criteria

Ideas such as focused manufacturing and the product and process matrix follow one of the key assumptions in the MS theory: competitive markets have variable needs that production systems must be able to satisfy. Operations and marketing management need to evaluate those needs and translate then into manufacturing capabilities needs (Slack, 1991).

Hill (1985) developed a framework that helps OM in evaluating and translating market needs into production needs. If competitive criteria vary from market to market, that is because they have different levels of importance in each market. Hill suggested that these criteria may be classified into qualifying and order-winning.

Qualifying criteria are objectives requiring a minimal performance level to the firm stay in the market. They do not guarantee the company to win orders but they prevent it from losing orders (Corbett and Van Wassenhowe, 1993). Improving these criteria beyond their qualifying level usually brings few competitive benefits to the company (Slack, 1991).

Order-winning criteria are objectives requiring a minimal performance level to the firm gain new orders. These are the key decision factors on which customers base their purchasing decisions. Improvements above their qualification level should probably lead to increasing demand (Slack, 1991).

The major advantage of this idea is that it integrates the marketing and manufacturing approaches. Competitive criteria earlier defined by marketing as 'price' and 'service' may be later translated into manufacturing objectives such as cost, quality and dependability (Corbett and Van Wassenhowe, 1993). These criteria are also dynamic that is they may shift according to environment changes. Order-winning criteria may become qualifying criteria and vice-versa. This dynamics require continuous environment control and process improvements to avoid the lose of competitiveness.

The major problem with this framework is that the competitive criteria follow only external requirements and not production capabilities (Spring, 1995). Later developments in the MS theory stressed the importance of production resources and capabilities as the major sources of competitive advantage (Hayes and Pisano, 1994). This is not considered in Hill's framework. Perhaps such framework should not only qualify the competitive criteria but also capabilities as order-winners or qualifiers. Another problem is the lack of empirical testing to corroborate so far this framework (Spring, 1995; Swink and Way, 1995).

New (1992) developed a framework similar to Hill's. This distinguishes upon 'Market Hygiene factors' and 'Competitive-Edge factors'. Market Hygiene factors correspond to the Qualifying criteria, while Competitive-Edge factors correspond to the Order Winning criteria. New (1992) suggested that the delivery of Competitive-Edge criteria depended on a set of decisions on manufacturing trade-offs. In spite of trade-offs not always disappearing, New (1992) sees their improvement may lead to better Competitive-Edge criteria.

The distinction upon different competitive criteria and, if possible, capabilities is essential to the management of trade-offs. First, it indicates the importance of distinct trade-offs to competitiveness. Second, it might qualify alternative actions to deal with trade-offs. For example, on deciding upon which objectives could be improved at the expense of others and which trade-offs should be improved at first.

1.2 The Manufacturing Strategy Process

From the late 80's, the development of MS concepts gave place to studies concerning more 'applied' issues such as the process and implementation of MS (Voss, 1992; Garvin, 1993; Anderson, Schroeder and Cleveland, 1991). Although Skinner (1969) developed a 'process of manufacturing policy determination', most studies in the 70's and early 80's had focused on theoretical aspects of MS and regarded its process and content to a second plane.

The process of MS received increasing attention from the late 80's as a number of studies defined some alternative frameworks (Sweeney, 1993; Garvin, 1993; Maruchek, Pannesi and Anderson, 1990; Horte, Lindberg and Tunalv, 1987). These frameworks integrate different levels of corporate and manufacturing planning. This in the broadest sense goes from the environment analysis to the implementation and audit of manufacturing programs. Table 1-2 summarises some of these manufacturing process frameworks.

General Steps	Skinner (1969)	Hill (1985)	Horte et al. (1987)	Maruchek, Pannesi & Anderson(1990)	Platts and Gregory (1990)	Garvin (1993)	Sweeney (1993)
Competitive Analysis	Environment Analysis		Competitive Analysis				
Corporate Strategy	Company Strategy	Company Objectives	Competitive Strategy	Corporate Strategy	Business Strategy	Business Strategy	Corporate Objectives
Marketing Strategy		Marketing Strategy					Marketing Strategy
Manufacture Mission		How to win orders?		Manufacturing Mission		Strategic Priorities	Target Service Standards
Manufacture Objectives	Manufacture Task		Manufacture Objectives	Manufacturing Objectives	Manufacture Objectives		
Manufacture Policies	Manufacture Policies	Process Choice	Structure and Infrastructure	Manufacturing Strategy	Manufacturing Strategy	Policies & Initiatives	
Manufacture Programs	Manufacture Operations	Manufacture Infrastructure		Tactical Planning	Manuf. Systems Design	Programs & Projects	Improvement Programs
Programs Implement.				Implement. (Next phase)	Implementation		Adapt Manuf. Structure
Performance Control	Results and Feedback				Operation and Audit		

Table 1-2: A review of manufacturing strategy process models.

The major difference among these frameworks is on their scope of analysis and implementation. They usually start with the corporate strategy and finish with the development or implementation of manufacturing programs. They have always two major assumptions that are (1) the MS process goes top-down and (2) the information provided by the process level '*n*' serves as input for the process level '*n+1*'. That summary suggests at least nine MS process levels, as follows:

1. **Competitive analysis**: The formal analysis of the external (competitive) and internal (structural) environments. It identifies the facts and forecasts that will influence the corporate strategy;
2. **Corporate strategy**: The definition of the major corporate objectives to be achieved by the end of the period;
3. **Marketing strategy**: The definition of the critical factors that may guarantee the marketing success;
4. **Manufacturing mission**: The first step of the MS itself. It defines the main objectives or strategy priorities to be achieved by manufacturing means;
5. **Manufacturing objectives**: It describes the manufacturing goals on dimensions such as cost, quality and flexibility. This is the contribution of production to the achievement of the corporate and marketing objectives defined;

6. **Manufacturing policies**: This is the heart of the process. It defines the basic choices and initiatives to support the achievement of manufacturing objectives. Policies concern different *decision areas* such as capacity, facilities and workforce (see Section 1.3.3);
7. **Manufacturing programs**: This is the definition of the activities for the implementation of manufacturing policies. Manufacturing programs consist in aspects such as activities, responsibilities, milestones and budget;
8. **Implementation**: It concerns the execution of the policies and programs from steps 6 and 7. Most authors do not extend their frameworks to this and the next phases;
9. **Performance control**: Skinner (1969) stresses the need for the assessment of the results achieved by manufacturing programs to support future modifications and improvements in the process.

Empirical studies (Maruchek, Pannesi and Anderson, 1990; Anderson, Schroeder and Cleveland, 1991) suggested that the successful formulation and implementation of a MS depends on some factors. The strategy should be understandable, measurable, durable and focused on a few key success factors. Both corporate and operations management should take part in the process (a 'team approach'). Mills et al. (1995) stressed the need for the participation and commitment of people and for the development of adequate procedures for the implementation, formulation and audit of the process.

1.3 The Manufacturing Strategy Content

The MS process concerns how to define and implement a MS. The content concerns the elements of this process. The major elements in the MS content relate to steps 4, 5 and 6 of the consolidated process model above. According to Schroeder, Anderson and Cleveland (1986), the MS content consists of four elements:

Mission: The manufacturing mission emanates from the business and marketing strategies. It is the main purpose of the manufacturing function. It is defined in step 4 of the process;

Manufacturing Objectives: These are the performance dimensions that sustain the achievement of a manufacturing competitiveness. They are defined in step 5 of the process;

Manufacturing Decision Areas: The manufacturing policies from step 6 of the process relate to different domains of the production system. A taxonomy of decision areas identifies these domains and their characteristics;

Distinctive Competence: A competence is a production capability with strong competitive performance and importance. Competencies are usually defined along with the manufacturing mission but, contrasting with the mission, they are singular.

The following sections discuss the manufacturing mission, objectives and decision areas. Section 1.4 reviews the literature on production capabilities and competencies.

1.3.1 Manufacturing Mission

According to Schroeder, Anderson and Cleveland's survey (1986), manufacturing managers usually agree on the meaning and objective of a 'manufacturing mission'. This mission states the objective and meaning of the manufacturing function for a given period. An example of manufacturing mission is presented in this study as

> *"... to produce a high quality product and provide superior delivery service to the customer by emphasising a preservative approach to quality assurance and by achieving short manufacturing cycle times. Manufacturing will establish the most people-oriented operation in the industry." (p. 410)*

The manufacturing mission emerges usually from the business strategy. It leads to the identification of the system's main capabilities and objectives and of the programs to be developed in the period.

1.3.2 Manufacturing Strategy Objectives

Manufacturing strategy objectives (or manufacturing strategy dimensions - MSDs) are the elements that define the competitive advantage based in manufacturing. The importance and performance of manufacturing activities depend on the achievement of these objectives (Slack, 1991). The definition of a typology of MSDs is essential to the building of frameworks for the MS planning and control.

The literature on OM has for long been concerned with the definition of MSDs typologies. These typologies are usually similar. The few differences among them reflect often different views on the importance and hierarchy of these objectives. The terminology referring to these objectives also varies, the same happening with their general denomination. Table 1-3 summarises some typologies with their specific terminology.

Objectives / Sources	Cost	Quality	Flexibility	Dependability	Speed	Additional Types
Hayes and Wheelright (1984) 'Performance Criteria'	Cost	Quality	Flexibility	Dependability		
Hill (1985) 'Performance Objectives'	Cost	Quality	Range of Products	Delivery Reliability	Delivery Speed	
Ferdows et al. (1986) 'Manufacturing Capabilities'	Cost	Quality	Flexibility	Delivery		
Swamidass and Newell (1987) 'Manuf. Strategic Dimensions'	Cost	Quality	Flexibility	Dependability		
Edmonson and Wheelright (1989) 'Performance Dimensions'	Cost	Product Performance	Flexibility	Dependability		Innovativeness
Platts and Gregory (1990) 'Performance Criteria'	Cost	Quality	Flexibility	Delivery Reliability	Delivery Speed	Product Features
Slack (1991) 'Performance Objectives'	Cost	Quality	Flexibility	Dependability	Speed	
De Toni, Filipini and Forza (1992) 'Competitive Priorities'	Cost	Quality	Flexibility	Dependability	Time	
Garvin (1993) 'Strategic Priorities'	Cost	Quality	Flexibility	Delivery		Service

Table 1-3: A review of typologies of manufacturing strategy objectives.

The most common dimensions along these typologies are *cost*, *quality*, *flexibility* and *dependability*. *Speed* is either considered a single category (Slack, 1991; Hill, 1985; De Toni, Filipini and Forza, 1992) or a sub-category of dependability or quality (Garvin, 1993; Hayes and Wheelright, 1984). *Innovativeness* is single category in Edmonson and Wheelright (1989) and a sub-category of speed in Slack (1991). Garvin (1993) refers to *service*. This is a sub-category of dependability or quality in Hayes and Wheelright (1984) and Slack (1991). Finally, Platts and Gregory (1990) enumerate *product features*. This is sometimes a sub-category of quality (Garvin, 1993; Slack, 1991).

The typology to be adopted in this study should summarise those above. It should be well balanced for reliability and scope that is neither too many nor too few categories should be included. Cost, quality, flexibility and dependability are major elements of all these typologies and should thus be considered. Speed is also included since it appears in a reasonable number of studies (four) and has been associated with recent ideas such as agile manufacturing. The remaining categories (innovativeness, product features and service) are in only one source and thus shall be considered sub-categories. Hence this study will adopt a typology of five MSDs with the following categories:

1. **Cost:** The total expenditure carried on the manufacturing and distribution of products, including expenses with raw materials, equipment, operational costs and delivery;
2. **Quality:** The measure of the achievement of standards in process performance, product features, customer services and other areas of the system;
3. **Flexibility**: The system's ability to change. Changes may concern new product features, process structure or activities;
4. **Dependability**: The ability to meet promised delivery schedules;
5. **Speed:** The time spent from the production order to the final product's delivery. It also refers to the time spent to introduce a new product (innovativeness).

This typology will make part of the research framework to guide the assessment and analysis manufacturing trade-offs as in the case studies.

1.3.3 Manufacturing Decision Areas

The determination of manufacturing policies to follow the mission and objectives is a complex task. Assessing and designing manufacturing systems is not an easy task. Even small systems have a complex network of units, relations, objectives and constraints. The determination of MS policies should thus follow a well-defined taxonomy of the different manufacturing decision areas (Correa, 1992).

The major taxonomy of manufacturing decision areas in the literature is that of Hayes and Wheelright (1984). Others have been provided in studies such as Haas (1987), Levary (1992), Garvin (1993), Buffa (1984) and Fine and Hax (1985). These taxonomies involve usually similar areas and levels. They are summarised in Table 1-4.

Decision Areas	Skinner (1974)	Buffa (1984)	Hayes and Wheelright (1984)	Fine and Hax (1985)	Haas (1987)	Levary (1992)	Garvin (1993)
Structural Decisions							
Capacity	X	X	X	X			X
Distribution			X			X	
Facilities	X	X	X	X	X	X	X
Process Technology	X	X	X	X	X	X	X
Vertical Integration	X	X	X				X
Infrastructural Decisions							
Human Resources	X	X	X	X	X		X
New Products		X	X	X	X	X	
Organisation Structure	X	X			X	X	X
PPC Systems	X		X		X		X
Quality			X	X			X
R&D					X		
Suppliers		X			X	X	X

Table 1-4: A review of taxonomies of manufacturing decision areas.

Table 1-4 suggests at least 12 decision areas to be used in manufacturing assessment and planning. Each area concerns a set of decisions or characteristics that must agree with the manufacturing mission and objectives, as indicated in Table 1-5.

Structural Decisions
1. *Capacity*: amount, timing, type. 2. *Distribution*: delivery times, reliability, vendors. 3. *Facilities*: size, localisation, specialisation. 4. *Process technology*: scale, flexibility, integration. 5. *Vertical integration*: direction, extent, balance.
Infrastructural Decisions
6. *Human resources*: selection, training, security. 7. *New products*: hard-off, start-up, modifications. 8. *Organisation structure*: communication systems, management policies. 9. *Production planning and control systems*: organisation, scheduling, control. 10. *Quality*: definition, roles, responsibilities. 11. *Research and development*: structure. 12. *Suppliers*: number, structure, relationship.

Table 1-5: Manufacturing decision areas and related decisions.

Hayes and Wheelright (1984) suggested dividing these areas into structural and infrastructural (see Table 1-5). Structural areas concern the 'architectural' configuration of the system and usually refer to long-term decisions. Infrastructural areas refer to short-term decisions and concern usually the system's organisation, planning and control (Leong, Snyder and Ward, 1990).

1.4 Production Capabilities

Production capabilities and their relationships with MS and performance is a key issue in today's OM literature. Their study is still recent and follows the well-called Resource-Based Theory from the business strategy literature.

This section reviews the major literature on production capabilities and competencies to highlight some issues that are important to this study. It consists in four parts concerning (1) the Resource-Based Theory, (2) resources and capabilities, (3) capabilities and competencies and (4) the relationship between competencies and business performance.

1.4.1 The Resource-Based Theory

The Resource-Based Theory probably started with Wernerfelt's (1984) work on the relationship between profitability and firm's resources. However, as he himself stated 11 years later (Wernerfelt, 1995), it was only by 1990 that other authors started investigating this issue. Prahalad and Hamel's (1990) study on the differences between a portfolio of competencies and a portfolio of businesses paved the way for a still growing research area.

The Resource-Based Theory follows the idea that resources are the major foundation of a firm's strategy (Grant, 1991). The firm's competitiveness should be assessed by its resources instead of products (Wernerfelt, 1984). This idea aims to explain why and how some companies appear always to explore market opportunities better than others, even when they use similar competitive strategies and have similar products. The answer is that a firm's competitiveness is based not on these factors but rather on its resources and capabilities. Long-term competitiveness relies on the development and exploitation of resources and capabilities (Stalk, Evans and Schulman, 1992; Prahalad and Hamel, 1990).

According to Grant (1991), the competitive strength of resources and capabilities relies on two factors that are (1) the long-term sustainability of the competitive advantage that they provide and (2) the firm's ability to appropriate the rent from these resources and capabilities. A resource-based approach in the strategy process should thus follow five steps: (1) identify and classify the firm's resources; (2) identify and classify the firm's capabilities; (3) evaluate the strategic potential of these resources and capabilities; (4) select the strategy that best exploits this potential and (5) identify the resource gaps that need still to be filled.

1.4.2 Resources and Capabilities

Within the Resource-Based Theory, resources are "... the stocks of available factors that are owned or controlled by the firm." (Amit and Schoemaker, 1993: 35). They are the basic units of analysis, the basic inputs in the process (Chandler and Hanks, 1994; Grant, 1991).

Wernerfelt (1984) and Zahra and Das (1993) divided resources into tangible and intangible. Tangible resources are easily observable and may be accurately measured. Examples of tangible resources are human assets, machinery and properties. Intangible resources are not directly observed or quantified. These are assets such as reputation and management skills. Manufacturing involves both tangible and intangible resources.

This theory views resources and strategy as complementary. The competitive strategy should ground on the availability of resources and resources should be adequate to marketing and strategy needs[2]. Strong resources have high uniqueness and low substitutability and may sustain a long-term competitive strategy (Zahra and Das, 1993).

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[2] That is probably the major difference between the Resource-Based Theory approach and the traditional manufacturing strategy approach. In spite of Hayes and Wheelright's 4 stages, the frameworks of manufacturing strategy process are usually top-down and do not consider the present status of the system.

Capabilities are the co-ordinated sets of resources aiming to perform some task or activity (Chandler and Hanks, 1994; Grant, 1991). Capabilities are any process, activity or function of a system such as product development, machine set-ups and quality inspection (Tinckenell and Radcliff, 1996). They require the co-ordinated gathering of resources towards one objective. The strength of capabilities depends on their ability to sustain the competitive strategy.

The next sections review the literature on capabilities and production capabilities and discuss the relationship between capabilities and MS.

1.4.3 Production Capabilities and Competencies

The firm's resources do not guarantee alone the superior competitive performance. This depends also on the ability to develop a set of capabilities to explore the resources and transform their potential into competitive advantage (Chandler and Hanks, 1994). For Hayes and Pisano (1994), the key to a sustainable competitive strategy (in manufacturing) is not technologies or 'TQM systems', but the development of superior capabilities. This agrees with Stalk, Evans and Schulman's (1992) idea of 'capabilities-based competition'.

According to Grant (1991), capabilities require the co-ordination of people and resources towards some task or activity. The strength of capabilities and resources is measured by at least four categories. These are (1) durability, that is their longevity; (2) transparency, that is the difficulty to competitors to identify the competitive advantage of the firm; (3) transferability, that is the possibility of competitors to acquire the same resources or capabilities that sustain the competitive strategy and (4) replicability, that is the possibility of competitors to develop internally these resources or capabilities. Amit and Schoemaker (1993) proposed a list of eight categories of measurement: scarcity, complementarity, low tradeability, overlap with strategic industry factors, inimitability, durability, appropriability and limited substitutability. Hayes and Pisano (1994) suggested that real capabilities should be recognised by customers and be difficult to imitate.

Gallon et al. (1995), divided capabilities into three categories. The first is market-interface capabilities, such as selling and advertising, that are used or visible in the marketplace. The second is infrastructure capabilities such as management systems and training, concerning the company's internal operations and technological capabilities. The third is technological capabilities that provide direct support to the product or service. These are divided further into applied science capabilities (fundamental research), design and development capabilities (such as CAD and project management) and manufacturing capabilities (such as quality control and scheduling).

Improving capabilities permits a better exploitation of resources and market opportunities. This is why firms should base their strategies on their available resources and capabilities (Chandler and Hanks, 1994). However, it is essential to compare these capabilities with the competitor's capabilities to guarantee that competitive advantage may be sustained in the long term (Grant, 1991). This leads to the idea of competencies.

Competencies are the critical capabilities that provide competitive advantage (Dawes, 1995). According to Prahalad and Hamel (1990), competencies (1) provide access to a wide variety of markets; (2) make a significant benefit to the customers and (3) are difficult to imitate. The most common distinction between capabilities that are competencies and the ones that are not concerns their performance in comparison to competitors. Competencies are the things that the firm does better than its competitors (Zahra and Das, 1993). Developing competencies usually takes a long time and requires continuous improvement and increasing efficiency in the exploitation of resources (Prahalad and Hamel, 1990).

1.4.4 Production Competence and Business Performance

The study of production resources, capabilities and competencies in the OM literature is in early stages. Most of these studies have been focusing on the relationship between production competencies and business performance.

Production competencies have been defined as the degree to which manufacturing supports the competitive objectives and priorities of the firm (Kim and Arnold, 1993; Vickery, Droge and Markland 1993). They measure the consistency between manufacturing and strategy. According to Vickery, Droge and Markland (1993), a production competence is a combined measure of the importance, performance and manufacturing role of a capability.

The most important debate in this literature concerns whether there is a correlation between production competencies and business performance. Cleveland, Schroeder and Anderson (1989) defined a production competence measure that relates to both the strength and importance of specific capability types. They correlated these measures with the marketing and financial performance of firms in comparison to their competitors. Albeit using a small sample (6 companies) and a log scale, they found a good correlation ($r^2 = .97$) between production competence and relative performance.

Vickery (1991) said that this method is inaccurate and suggested a modified measure of business performance. Vickery suggested that the 'deceptively' high correlation found by Cleveland, Schroeder and Anderson is due to both variables - production competence and performance - were not independent. The business performance measure captured elements of the production competence measure. Nevertheless, Vickery found still a strong relationship between these variables, indicating that production competence is probably a valuable construct to explain the manufacturing contribution on performance. This was emphasised again by Vickery, Droge and Markland (1993).

Kim and Arnold (1993) returned to the question with data from the 1990 US Manufacturing Futures Survey. They defined some competence indexes similar to those of Cleveland, Schroeder and Anderson (1989) and correlated these indexes with four performance measures. They found a low correlation between production competence and the overall performance. They suggested that other factors such as environment and management may have a more significant impact on performance. However, they found a significant correlation between production competence variables and two performance measures that are return over assets and profit ratio. The other two measures, growth ratio and market share, presented low correlation with production competence. That correlation was more significant in the electronics sector than in the machinery sector. These findings may suggest that production competencies have a more significant correlation with some performance measures and business sectors than with others.

1.5 Chapter Conclusions

This chapter reviewed the literature on MS that is most relevant to this study. It is divided into 4 areas concerning MS concepts, MS process, MS content and production capabilities.

The concepts reviewed form the background of MS. They are focused factories, the stages of manufacturing effectiveness, the production-process matrix and the qualifying and order winning criteria. These ideas may be used later in the study as a comparative basis for the shaping of hypotheses and conclusions. The practices evidenced in the case studies may also be compared for their correspondence to these concepts.

Concepts such as focused manufacturing and the production-process matrix have still major importance in the literature and have been re-addressed in recent studies (Wathen, 1995; Spencer and Cox, 1995). It seems that the MS literature has been more concerned with revising and adapting the old concepts to a new context than with creating new ideas (Voss, 1995; Swink and Way, 1995).

The most important elements in the MS process and content for this study are the taxonomies of MSDs and of manufacturing decision areas. MSDs are an essential part of the research framework. The trade-offs in study refer to their relationships in the context of operations systems. The decision areas should be used along the investigation to help in the classification of the data referring to different areas of the companies. Research in this area seems to be less active than with MS concepts. The current research seems to be more concerned with formal aspects of MS process and content (such as the definition of taxonomies) than with their analysis along with new concepts and contexts.

Some recent studies in MS concern the investigation of production capabilities and their relationship with the business strategy. The relationship between capabilities and trade-offs is a major element of the research framework. Concerning the OM literature, the study of production capabilities is quite recent and still require some extensive development.

This review suggests some questions that may be open for further investigation in this and in subsequent studies. The questions on the scope of MS are the following:

1. There seems to be a major difference between the Focused Factories approach and the Stages of Manufacturing Effectiveness approach. The Focused Factories' seems more reactive, suggesting to adapt the system to competitive and operational circumstances of the firm. The 'stages' approach seems more proactive by suggesting improving the system to meet those criteria. One could investigate whether these ideas are complementary or incompatible and whether there is a 'best' approach between the two;

2. There is no literature so far suggesting a link between (a) the Stages of Manufacturing Effectiveness and/or the Generic Manufacturing Strategies and (b) advanced manufacturing strategies such as Mass Customisation, Business Process Re-Engineering and Time-Based Strategies. Is Mass Customisation typical of companies in the third stage? Does BPR correspond to any of Sweeney' strategy types in particular?

3. The relationship between (a) resources and capabilities and (b) objectives performance is still controversial. Furthermore, those studies do not include the idea of trade-offs or any other 'combination' of objectives. One could investigate how to consider the development of resources and capabilities within the MS process and how this should affect the system's performance.

Chapter 2 - Manufacturing Flexibility

Chapter 2
Manufacturing Flexibility

Introduction

Manufacturing flexibility is a subject of growing importance in OM. Specially from the 80's, factors such as the emergence of new technologies qualified flexibility as a major answer for increasing levels of variety and uncertainty in industrial markets. The OM literature focused initially on formal issues on the flexibility concept and dimensions. Now, it has turned to more operational issues on the flexibility assessment and implementation.

This chapter consists in five sections. Section 2.1 discusses the concept and justification of manufacturing flexibility. Section 2.2 discusses the main flexibility theory. That is aspects such as flexibility types, levels and dimensions. Section 2.3 deals with the flexibility methodologies and technologies. Section 2.4 discusses the flexibility assessment and measurement. Section 2.5 discusses the relationship between flexibility and MS.

2.1 Concept and Justification

2.1.1 The Concept of Manufacturing Flexibility

The economics literature was the first to investigate flexibility in the context of industrial firms. This has probably started with Stigler's (1939) study on the impact of flexibility on cost curves. He stated that flexibility varies inversely with the firm's total costs. He was the first to investigate the trade-off between production costs and variety. Hart (1942) defined flexibility as a response to demand uncertainty. Twenty years later, Marschak and Nelson (1962) extended this idea: flexibility is the ability to cope with all forms of turbulence in the market. Jones and Ostroy (1984: 13) defined flexibility as "... a property of initial position. It refers to the cost of moving to various second period positions."

It was from the 80's that the OM literature started paying an increasing attention to flexibility. Many studies attempted to construct a theory of flexibility in the context of OM and strategy. Three types of concepts of flexibility may be identified in these studies.

The first type reflects the ideas from the economics literature. Here, *flexibility is the ability to adapt to environmental changes or uncertainty*. Zelenovic (1982: 323) followed this view: "The flexibility of a production system is a measure of its capacity to adapt to changing environmental conditions and process requirements". Sethi and Sethi (1988: 9) stated that "Flexibility of a system is its adaptability to a wide range of possible environments that it may encounter."

The major problem with this concept is that it does not embrace the 'proactiveness' suggested in the MS literature. Manufacturing systems should not *adapt* to changes but *cope with* them. Gerwin (1993: 408) followed this view: "Flexibility is not just an adaptive response to an uncertain environment. It has a proactive function in creating uncertainties that competitors can not deal with." Thus, there is a second type of concepts for which *flexibility is the ability to cope with changes*. This is in Gupta and Goyal (1989: 120): "Flexibility is defined as the ability of a manufacturing system to cope with changing circumstances." Elango and Meinhart (1994: 118) followed this idea: "Flexibility is the ability of a manufacturing firm to cope with changing circumstances." According to Fensterseifer (1992: 3), the flexibility of a system is "... its ability to cope with the uncertainties of a changing environment." He suggested that flexibility is only necessary if changes are uncertain. If changes are predictable, flexibility is not necessary.

The third concept is more subjective and demanding than the former. Here, *flexibility is the ability to change* (Slack, 1987). Upton (1994: 73) was more explicit: "Flexibility is the ability to change or react with little penalty in time, effort, cost or performance". Crowe (1992) followed a similar approach when defining mix and volume flexibility. Van Dijk (1995: 115) stated that "Flexibility can be defined as the ability to shift promptly to one process and/or product conformance to another."

On the context of MS, the second concept is better than the first because it follows the proactive approach. The second and third concepts may be combined, since the second concerns *what* flexibility is and the third concerns *how* it is obtained. Therefore, ***flexibility is the ability to cope with unpredictable environmental changes by changing the system's characteristics***. This definition summarises the many ideas in the literature.

Flexibility is thus essentially related to change. According to Correa (1992), variety and uncertainty are the major parameters of change. To understand why flexibility is important in OM it is thus necessary to understand what is the role of change, variety and uncertainty in this context.

2.1.2 Change

In the organisations' context, change is any modification in the characteristics of a system or its environment. Eppink (1978) classified changes into reversible and irreversible. Reversible changes occur around a stable mean. Irreversible changes concern new facts and trends. Correa (1992) classified changes into planned and unplanned; planned changes result from management's decisions. Unplanned changes are uncertain and thus demand flexibility. He classified the sources of unplanned changes into seven groups: operations process, labour, suppliers, customers, society, corporation and competitors.

According to Correa (1992), changes have different levels of uncertainty and variety. Uncertainty levels reflect the quality of the information (or forecast) that one has about changing events. Variety is the range of states that a variable may assume. This is characterised by at least four dimensions: (1) size, that is the absolute modification in the variable's value in a given period; (2) novelty, that is the originality or strangeness of the change; (3) frequency, that is the number of relevant change occurrences in a period and (4) speed, that is the relative modification in the variable's value in a period.

2.1.3 Uncertainty

According to Downey and Slocum (1975: 571), uncertainty is "... a state when an individual defines himself as engaging in directed behaviour based upon less than complete knowledge of his existing relationship with this environment..." In behaviourist terms, it represents the individual's sense of loosing control of the environment, its changes and consequences. Environmental uncertainty is the major justification for flexibility. In the absence of uncertainty, one could optimise all activities for the long-run performance, with no need for flexibility options (Fensterseifer, 1992).

Wernerfelt and Karnani (1987) and Chen, Calantone and Chung (1992) provided examples of environment uncertainty sources. These are classified into four categories:

1. **Demand uncertainty:** Product diversity, short life-cycles, buyer concentration, market size, product design, distribution channels;
2. **Competitors uncertainty**: Competitors strategy, new entrants, substitute products;
3. **Supply uncertainty**: External suppliers performance, internal technology and resources availability;
4. **Externalities**: Social pressures, government intervention.

One may deal with each uncertainty type through the use of flexibility or reduction strategies. Flexibility strategies create future options to cope with unexpected changes. Reduction strategies moderate or eliminate the impact of changes in the system.

Studies such as Swamidass and Newell (1987) and Gerwin (1993) investigated the relationship between uncertainty and flexibility. Newman et al. (1993) put uncertainty and flexibility in the opposite sides of a pivot. That means flexibility should match the environment's uncertainty.

The following are examples of reduction strategies relating to those types of uncertainty (Goldhar and Jelinek, 1985; Correa and Slack, 1994; Nemetz and Fry, 1988):

1. **Demand uncertainty:** Product differentiation, niche marketing, focused factories, inventories management, forecasting;
2. **Competitors uncertainty:** Product differentiation, low cost strategies, short lead-times;
3. **Supply uncertainty:** Work-in-process management, preventive maintenance, suppliers development;
4. **Externalities:** Short lead-times, environment monitoring, industrial relations.

Section 2.2.1 discusses the relationship between uncertainty and flexibility types.

2.1.4 Variety

Increasing variety needs have been usually a major concern in OM. The progress through the main OM paradigms (taylorism, fordism, just-in-time, lean manufacturing) comes in great extent from the need to cope with increasing variety in operations. Many OM concepts and techniques focus on the management of variety.

For Yeh and Chu (1991), the most important impact of increasing parts variety is on cost. According to Kekre and Srinivasan (1990), this is compensated sometimes with the profits generated by new products. Yeh and Chu (1991) analysed also the impact of variety in other performance objectives. Increasing variety did not affect quality performance. It affected partially the product flexibility and had a negative impact on dependability and volume flexibility. Yeh and Chu (1991: 39) reinforced Stigler's trade-off between variety and cost: "... broadening product lines increases a company's power to compete in the market but also causes the company to lose its cost advantage."

Correa (1992) emphasised this trade-off as well. He proposed that broadening product lines increase fixed (machinery), variable (set-ups, inventories, quality control) and indirect costs (purchasing, warehousing, administration). Skinner (1974) considered this trade-off the major justification for focused factories (see Section 1.1.1). This trade-off is further discussed in Chapter 3.

Since the system's impact of variety is mainly negative, OM should define strategies to cope with it. As with coping with uncertainty, coping with variety may lead to flexibility strategies such as fast set-up times and small lots production or reduction strategies such as focused manufacturing, parts standardisation and modular production. Yeh and Chu (1991) discussed many of such reduction strategies.

2.1.5 Flexibility and Change

One may deal with variety and uncertainty though flexibility or reduction strategies. Reduction strategies aim usually to reduce the impact of changes, reducing the need for flexibility. Thus, the amount of flexibility that is necessary depends on the level of environment uncertainty and variety minus the effect of reduction strategies. The major advantage of reduction strategies over flexibility is in their lower implementation cost.

Correa and Slack (1994) and Yeh and Chu (1991) provided examples of reduction strategies relating to variety and uncertainty as following:

1. Monitoring and forecasting, to minimise uncertainty;
2. Co-ordination and integration among different production stages;
3. Focus on manufacturing, to reduce variety needs;
4. Sub-contracting, to transfer the responsibility on coping with change;
5. Negotiation and promotion, to reduce uncertainty and variety needs;
6. Preventive maintenance, to avoid equipment breakdowns.

Production managers usually prefer to apply reduction strategies rather than flexibility (Slack, 1987). According to Hill and Chambers (1991), flexibility is most appropriate when reduction strategies can not cope fully with the impact of uncertainty and variety.

The next section discusses the types, dimensions and characteristics of flexibility. Each type corresponds to specific types of change, variety and uncertainty.

2.2 Manufacturing Flexibility Theory

2.2.1 Flexibility Types

Flexibility taxonomies have an important role in today's OM. They are necessary for the assessment and development of flexibility strategies to deal with different types of change. The literature provides already some comprehensive surveys comparing many different typologies (Adler, 1985; Sethi and Sethi, 1988; Ramsesh and Jaikumar, 1991; Crowe, 1992). Table 2-1 summarises the 11 types that are most frequent across these studies.

Sources / Flexibility Types	Browne et al. (1984)	Lim (1987)	Slack (1987)	Sethi & Sethi (1988)	Azzone & Bertele (1989)	Ramsesh & Jaikumar (1991)	Chen, Calantone and Chung (1992)	Gerwin (1993)
Product	X	X	X	X	X	X	X	X
Mix			X				X	X
Delivery			X					
Production				X	X			
Volume	X	X	X	X	X	X	X	X
Expansion	X	X		X	X	X	X	
Process[1] [Materials] [Operations]	X	X		X	X	X	X	X
Programming				X		X	X	
Rerouting[2] [Handling]	X	X		X	X	X	X	X
Machine	X	X		X		X	X	
Labour		X				X	X	

Table 2-1: Manufacturing Flexibility Taxonomies

Each flexibility type relates to specific types of change, variety and uncertainty. The level of implementation of each type depends on the nature of these variables. The eleven types from the summary in Table 2-1 are the following:

1. **Product flexibility**: the ability to introduce or modify products economically (Slack, 1987; Browne et al., 1984);
2. **Mix flexibility**: the ability to change the range of products made within a period (Slack, 1987);
3. **Delivery flexibility**: the ability to change delivery dates (Slack, 1987);

[1] The ability to produce using different process sequences (operations flexibility) and the ability to produce using different raw materials (materials flexibility) are sometimes refereed as two different concepts and, other times, as one single concept (process flexibility). In order to simplify the present taxonomy and its further application, the joined concept was preferred.

[2] Rerouting flexibility is an extended concept of handling flexibility. It depends both on transport systems flexibility and duplicated assignments.

4. **Production flexibility**: the ability to produce economically a range of part types (Sethi and Sethi, 1988);
5. **Volume flexibility**: the ability to operate economically, in the short term, at different product volumes (Chen, Calantone and Chung, 1992; Browne et al., 1984);
6. **Expansion flexibility**: the ability to build and expand the system's capacity (Browne et al., 1984; Sethi and Sethi, 1988);
7. **Process flexibility**: the ability to produce a given set of parts using different process sequences and/or materials (Chen, Calantone and Chung, 1992; Browne et al., 1984). [**Materials flexibility**]: the capacity to produce parts with alternative raw materials (Ramsesh and Jaikumar, 1991). [**Operations flexibility**]: The ease of changing the sequence of operations necessary to complete a set of parts (Sethi and Sethi, 1988);
8. **Programming flexibility**: the ability to operate unattended for a given time (Chen, Calantone and Chung, 1992; Ramsesh and Jaikumar, 1991);
9. **Rerouting flexibility**: the ability to process a given set of parts using alternative routes (Chen, Calantone and Chung, 1992; Ramsesh and Jaikumar, 1991). [**Handling flexibility**]: the ability to transport different parts efficiently through the facilities as far as the unloading or storage areas (Sethi and Sethi, 1988);
10. **Machine flexibility**: the machine's ability to perform various types of operations without prohibitive efforts in making changes from one to another (Browne et al., 1984; Sethi and Sethi, 1988);
11. **Labour flexibility**: the workforce's ability to perform a wide range of tasks efficiently (functional). The readiness with witch the number of workers can be changed (numerical) (Chen, Calantone and Chung, 1992; Ramsesh and Jaikumar, 1991).

These types are interdependent. One ability may increase or decrease as a result of other's increase. Production flexibility relies on labour and machine flexibility. Mix flexibility depends on rerouting, programming and process flexibility. Sethi and Sethi (1988) provided some examples of these relationships. That means OM may increase some flexibility types through changing others. However, increasing a type may also decrease other types. Volume flexibility may decrease if one increases the process, rerouting or handling flexibility by new equipment purchases (increasing fixed costs). Thus, one may identify potential trade-offs between some flexibility types.

The use of such taxonomies is essential in flexibility management. Lim (1987) discovered that managers that had implemented flexible manufacturing systems were able to nominate not more than five types (machine, process, product, rerouting and volume). This may explain the lack of understanding about the potential of flexibility in practice.

The relationship between flexibility types and change, variety or uncertainty types has also been discussed in some studies. Gerwin (1993) related flexibility types to uncertainty and strategic objectives' types, as presented in Table 2-2:

Type of Uncertainty	Strategic Objective	Flexibility Dimension
Market acceptance of kinds of products	Diverse product line	Mix
Length of product life cycles	Product innovation	Product
Aggregate product demand	Market share	Volume
Machine downtime	Customers due dates	Rerouting
Characteristics of materials	Product quality	Materials

Table 2-2: Uncertainties, strategic objectives and flexibility dimensions.
Source: Gerwin (1993)

2.2.2 Flexibility Capabilities

Flexibility capabilities are the system's functions or activities that sustain the development of flexibility types. While each flexibility type relates to a number of different capabilities, it is possible to identify the capabilities that best relate to each type.

Major examples of flexibility capabilities are machine set-ups, product development, materials handling and scheduling. Naturally, these activities relate not only to flexibility but to other dimensions as well. This section focuses on the relationship between these capabilities and flexibility.

Perhaps because of the novelty of the idea of capabilities, the literature does not investigate flexibility capabilities in the same extent as, for example, flexibility resources or measures. The following relationships between flexibility capabilities and types came from studies focusing on general issues on flexibility instead on specific taxonomies. Thus, while this section summarises the major ideas in this literature, it is important to point out the lack of development in this issue so far and the need for more comprehensive taxonomies of flexibility capabilities in the literature.

The production capabilities best related to flexibility types in the literature are as follows:

Flex. Type	Flexibility Capabilities
Product	Product design and modification (Slack, 1991);
Mix	Production planning and control (Slack, 1991);
Delivery	Production scheduling (Slack, 1991);
Production	Line set-ups (Gupta and Goyal, 1989; Sethi and Sethi, 1988); product development (Gupta and Goyal, 1989);
Volume	Forecasting; sub-contracting (Slack, 1991); line set-ups (Barad and Sipper, 1988);
Expansion	Capacity/facilities mgt (Chen, Calantone and Chung, 1992; Browne et al., 1984);
Process	Parts transportation (Barad and Sipper, 1988); line set-ups (Browne et al., 1984);
Programming	Production control (Chen, Calantone and Chung, 1992; Sethi and Sethi, 1988);
Rerouting	Parts transportation (Barad and Sipper, 1988; Sethi and Sethi, 1988; Stecke and Raman, 1995);
Machine	Machine set-ups (Barad and Sipper, 1988; Sethi and Sethi, 1988; Stecke and Raman, 1995; Browne et al., 1984);
Labour	Workforce skills (Chen, Calantone and Chung, 1992; MacInnes, 1988; Frazelle, 1986).

Table 2-3: Flexibility types and capabilities

2.2.3 Flexibility Dimensions

When investigating the relationship between flexibility and uncertainty, Jones and Ostroy (1984: 13) stated that "One position is more flexible than another if it leaves available a larger set of future positions at any given level of cost". Flexibility implies not only a number of options but also a time and cost on assuming these options. It has two dimensions.

Following this idea, Slack (1983) proposed that one should assess the performance of a flexibility type by two measures: the *range* of states it may adopt and its *response*, that is the time and cost it takes to change from one state to another[3]. Given enough time or resources, firms may assume any state and cope with any change. Flexibility would not be necessary as reactive changes would always be successful (Fensterseifer, 1992).

Slack (1988) suggested the use of 'range-response curves' for the assessment of flexibility. Slack and Correa (1992) successfully applied these curves to assess four flexibility types across two plants that used different production paradigms (pulled production and pushed production).

[3] Just like there is a trade-off between range and response flexibility, there is another between response time and cost. In a static situation, the time taken for a change usually increases if the cost of this change decreases and vice-versa.

Slack (1987) observed also a tendency of production managers to focus on the development of response flexibility only. This is a consequence of the lack of understanding of the potential that flexibility has in practice, as noted by Lim (1987). Flexibility has two dimensions and should be assessed in such way.

2.2.4 Flexibility Assessment: Areas and Levels

The assessment of flexibility is not an easy task. Flexibility depends on the performance of a large set of interrelated resources and capabilities relating to different areas and levels. It is a machine's function as well as a system's function. The different flexibility types may be assessed along different levels, in spite of each type is best related with a specific level.

Gerwin (1987) proposed that flexibility might be assessed along five alternative levels. Each level is best related with specific types and implies different approaches for the development of flexibility. He proposed the following taxonomy of levels:

Level 1 - the individual machine;
Level 2 - the function (e.g. forming, assembling);
Level 3 - the manufacturing process for a single or a group of products;
Level 4 - the factory (manufacturing function);
Level 5 - the entire production system.

Gerwin (1987) suggested that the system's overall flexibility should be gradually assessed from level 1 to level 5.

Slack (1987) suggested a different taxonomy. He proposed that flexibility should be assessed along two levels of aggregation as follows:

1) A ***resources' level***, involving areas such as technology, labour and infrastructure;
2) A ***system's level***, involving the total manufacturing function.

The resources level corresponds to Gerwin's levels 1, 2 and 3. The system's level corresponds to Gerwin's levels 4 and 5.

These taxonomies concern different views. Gerwin focused on the variety of assessment levels, while Slack seemed more concerned with the various areas that may relate to each level. Given their singularities, it seems interesting combining these models into one framework, as suggested in Table 2-4.

Resources Level	Technology	Labour	Infrastructure	
Machine				
Function				
Process				
System's Level	Technology	Labour	Infrastructure	Management Systems
Factory				
Entire System				

Table 2-4: A framework for manufacturing flexibility analysis

Each framework's cell may contain a measure of each dimension (range/response) of each flexibility type. Additionally, as following discussed, this measure may concern any of three types of performance (required, potential and actual). Naturally, given the number of flexibility levels, types, dimensions and performance types involved, the use of this chart can not be direct. The completion of this chart would demand the calculation of 3 performance types for 2 dimensions of 11 flexibility types in 17 cells, that is 1,122 values.

Such a framework could be used instead to assess the performance of flexibility variables (each variable as a combination of performance type and flexibility dimension, type and cell) already defined as the system's priorities. Only a small portion of those 1,122 variables should be relevant. Furthermore, each flexibility type is best related to one level which should minimise further the number of relevant variables. The use of this framework should thus follow the identification of the relevant flexibility variables in the system.

In fact, such large number of variables results from the variety and complexity of flexibility frameworks in the literature. It reflects the large number of taxonomies, classifications, approaches and other distinctions that have been developed. While these frameworks may be useful for the flexibility management, such complexity may lead also to some confusion, specially in practice. This suggests that the development of more general and operational frameworks (combining existing ones) seems increasingly necessary.

2.3 Flexibility Technologies and Methodologies

The process of implementation of flexibility have been receiving increasing attention in the literature. Advances in OM technologies and methodologies have been providing a growing range of flexibility means. The choice and implementation of appropriate technologies and methodologies for flexibility seems each time more complex. Its success relies on many factors such as the organisational structure, management, workforce and competition practices (Upton, 1995).

Sources of flexibility may be divided into 3 groups: technologies, methodologies and other flexibility types. The technologies concern a range of new automating systems usually referred as Advanced Manufacturing Technologies (AMTs). The impact of AMTs on flexibility is so effective that they are often called 'Flexible Technologies'. Different AMTs may operate stand-alone or integrated into broad structures such as Computer Integrated Manufacturing Systems and Flexible Manufacturing Systems.

Developing flexibility may also concern OM methodologies. Some of these methodologies, such as cellular manufacturing and fast set-ups, are associated usually with just-in-time systems. Others consist in management policies such as training and subcontracting that may also provide flexibility benefits.

Finally, since the flexibility types are interdependent, one may develop some types by increasing others. These relationships depend mostly on the context of the organisation. Nevertheless, the literature points out some relationships that may characterise with more frequency specific pairs of types. Table 2-5 summarises the relationships between flexibility types and sources as in different OM studies.

Flex. Types / Sources	Browne et al. (1984)	Frazelle (1986)	Gerwin (1987; 1993)	Sethi and Sethi (1988)	Chen, Calantone and Chung (1992)
1. Product	T8; F10	T1; T4; T2	T6	T2; T3; T4; M2; M5	T2; T4; F10; F9
2. Mix		T5	M1; M3; F10; F11		F10; F9
3. Delivery					
4. Production				F10; F11 T6; F9; T8	
5. Volume	T6; T9; M2; F9	M2; T9	M5; F11	T6; F9	F11
6. Expansion	M2; F9; T9; T7			M2; T6	T6; T9; F8
7. Process	F10; T6		T8	M1	M1
8. Programming				F9; T8	F10; F9; T8
9. Rerouting	T9; M5	T9	M5	T9; T8; T6; T9; T7	T9
10. Machine	T7			T6; T7	T7; T6; T9
11. Labour		M4			M4

Table 2-5: A summary of flexibility types and their sources

The codes in Table 2-5 correspond to the following sources (following discussed):

Technology types (Ti)	**1 Computer integrated manufacturing systems (CIMS);** 2 Computer aided design (CAD); 3 Computer aided manufacturing (CAM); 4 Computer aided process planning (CAPP); **5 Flexible manufacturing systems (FMS);** 6 Numerical control (NC); 7 Automatic loading of parts and tools; 8 Computerised control systems (CCS); 9 Materials handling and storage systems.
Methodology types (Mi)	1 Design for manufacturability; 2 Group technology and cellular manufacturing; 3 Set-up time reduction; 4 Human resources policies; 5 System's management policies.
Flexibility types (Fi)	Types 8 to 11 as in the first column of Table 2-5

2.3.1 Flexibility Technologies

2.3.1.1 Computer Integrated Manufacturing Systems

A Computer Integrated Manufacturing System (CIMS) is the computer assisted integration of all system's activities, including design, planning, process and delivery. The integration of these activities means the ability to exchange on-line data between any parts of the system. Complete CIM systems are still more idea than reality in today's typical manufacturing systems (Blois, 1985; Ashayeri, Teelen and Selen, 1995).

A CIMS integrates a broad range of technologies that may also operate stand-alone. Among these technologies are: (1) management technologies such as Materials Requirements Planning (MRP) and Group Technology (GT); (2) designing, planning and controlling technologies such as Computer Aided Design (CAD) and Computer Aided Process Planning (CAPP) and (3) operative technologies such as robots and Flexible Manufacturing Systems (FMS) (Ashayeri, Teelen and Selen, 1995). The range of performance measures that may be affected by CIMS is very wide and depends on the quality of the equipment and the management and integration of its units.

The major technologies associated with CIM systems are following discussed.

2.3.1.2 Computer Aided Design - CAD

Computer aided design is the use of computerised software to help in the design and modification of products and processes (Meredith, 1987a). According to Wiley (1986), the major benefits of CAD systems are (1) increasing design productivity and (2) the building of a data base of parts and processes. CAD systems have usually advanced features such as interactive graphics, three-dimensional simulation and digital recording of graphics. Graphics can be modified, saved and printed with good quality, speed and reliability (Jelinek and Goldhar, 1983).

The basic advantages of CAD over traditional design systems are more advanced simulation, easier customisation, higher productivity and increasing product flexibility (Frazelle, 1986; Gerwin, 1987; Chen, Calantone and Chung, 1992; Buxey, 1991).

2.3.1.3 Computer Aided Manufacturing - CAM

Computer aided manufacturing is the use of computerised systems to produce the information, or parts-programme, that guides the manufacturing process of products or part types. This is usually inserted on or transferred to numerically controlled machines (NCs) as set-up specifications (Blois, 1985; Cainarca, Colombo and Mariotti, 1990).

According to Buxey (1991), CAM systems concern also applications such as tools and fixtures designing and the generation of comprehensive process plans and instructions. As with CAD, the major benefit of CAM is its lower design time and cost that increases the product flexibility (Sethi and Sethi, 1988).

CAD and CAM work usually integrated. Their combination minimises the time and cost to design and plan the process of new and modified products. This integration means the use of a common data base to share and transfer information between both systems (Blois, 1985). With CAM data, designers may take in consideration product characteristics and process requirements to detect design flaws and inadequacies in an early stage (Jelinek and Goldhar, 1983). This is a major example of the integration between project and manufacturing that is often stressed in the literature.

2.3.1.4 Computer Aided Process Planning - CAPP

Computer Aided Process Planning (CAPP) systems aid the generation of production routings and instructions. A CAPP system assigns the machines and defines the sequence, timing and instructions for the operations for the making of a product or part. The implementation of CAPP systems requires the collection of a large amount of data such as shop-floor layouts, machine attributes and the design and requirements of each part type. Because of the need for these data, CAPP systems work better when integrated with CAD and CAM systems. In fact, they are used often as a link between CAD and CAM (Vonderembse and Wobser, 1987; Meredith, 1987a).

As with CAD and CAM, the major benefit of CAPP is increasing product flexibility. They minimise the time and cost of new products development and increase the ability to manage a large parts' variety (Frazelle, 1986; Sethi and Sethi, 1988; Chen, Calantone and Chung, 1992). They also minimise production costs, set-up and throughput times with their ability to select the most appropriate machines, paths and sequences for each part.

2.3.1.5 Flexible Manufacturing Systems - FMS

According to Gilbert and Winter (1986), a Flexible Manufacturing System (FMS) is (1) a combination of multiple work stations equipped with automated materials handling and tool changing systems, (2) capable of economically producing a family of parts within a wide range of volumes and (3) operated under integrated computer control. According to Huang and Chen (1986), FMS operate economically in a context of low to medium volume, different process cycles and different operation sequences.

Flexible Manufacturing Systems integrate independent technologies with different manufacturing functions. A typical FMS consists usually of four components (Kaighobadi and Venkatesh, 1994; Grahan and Rosenthal, 1986):

1. Independent, numerically controlled machine tools (NCs), equipped with
2. Automatic loading systems, linked by
3. An automated material-handling system, all controlled by a
4. Computerised control system.

The performance of an FMS depends on the appropriate operation and integration of its components. A typical FMS process begins with production orders being loaded in a central computer that decides upon the overall sequence of operations to be carried out each part. The handling system directs the parts to the appropriate NC machines. The parts are loaded by the attached loading system. The central computer controls the sequence of operations until the end of the process. (Blois, 1985)

FMS affect a broad range of performance measures. This effect results both from the impact of each component and from their integration as a system. An FMS may increase directly or indirectly all flexibility types and bring benefits such as (Huang and Chen, 1986; Wiley, 1986; Das and Khumawala, 1989; Boer, Hill and Krabbendam, 1990):

- Lower fixed and variable costs such as materials, labour, and work-in-process;
- Lower lead times, set-up times and delivery times;
- Higher delivery reliability;
- Higher product quality and improved quality management;
- Better monitoring and process control and improved logistics.

Achieving these benefits depends on the correct planning, design, implementation and management of the system. Common obstacles to the success of a FMS concern economical, technical and organisational factors (Boer, Hill and Krabbendam, 1990).

2.3.1.6 Numerical Control - NC

A numerically controlled manufacturing process is a set of programmable machine tools readily adaptable to set-up changes (Wiley, 1986). The set-up readiness of NC machines increases the system's flexibility, reliability and speed (Gilbert and Winter, 1986). These technologies are in three levels, depending on the type of computer control attached to the machine tools (Meredith, 1987a; Cainarca, Colombo and Mariotti, 1990):

1. Numerical control (NC), when machine tools are controlled by punched tapes;
2. Computer numerical control (CNC), when machine tools are controlled by dedicated computers;
3. Direct numerical control (DNC) when machine tools are integrated and controlled by a central computer.

Numerically controlled machines are major sources of flexibility. These technologies bring benefits such as increasing product, volume, expansion, machine, process, rerouting and production flexibility (Browne et al., 1984; Sethi and Sethi, 1988; Gerwin, 1987; Chen, Calantone and Chung, 1992).

2.3.1.7 Automatic Loading of Parts and Tools

These technologies are briefly discussed in Section 2.3.1.5.

2.3.1.8 Computerised Control Systems - CCS

Computerised control systems are the 'management devices' of an FMS. They usually consist in a central computer that integrates a number of functional controllers. These controllers may be associated to different system's levels, as (Primrose and Leonard, 1986):

1. Machine tool controllers, operating the machine functions;
2. System controllers, operating inter-machine functions;
3. Management control, scheduling the work flow and
4. Outside (or central) control, directing work to and from the overall FMS.

The benefits of CCS vary according to their objectives and specifications. They usually concern increasing reliability and dependability and minimising the cost and time of production planning and control. They may increase flexibility types such as rerouting, product, programming and production flexibility (Gerwin, 1993; Sethi and Sethi, 1988; Chen, Calantone and Chung, 1992; Browne et al., 1984).

2.3.1.9 Material Handling and Storage Systems

Material handling systems consist in serial and random access technologies (Das and Khumawala, 1989). Serial access systems are automated conveyors or monorails that transport material and parts through fixed routes in the shop-floor. These are usually cheaper and easier to control than random access systems. Random access systems consist in automated guided vehicles (AGVs) such as carts and robot carriers that are able to visit any machine station in an FMS. They are trackless and self-propelled. Their major benefit is increasing rerouting flexibility. One has to be careful on the design and planning of such systems since failures in their performance may affect the entire production system (Kaighobadi and Venkatesh, 1994; Vonderembse and Wobser, 1987).

Automated guided vehicles are valuable sources of rerouting flexibility. They may also affect the volume, expansion, and machine flexibility (Browne et al., 1984; Sethi and Sethi, 1988; Frazelle, 1986; Chen, Calantone and Chung, 1992).

2.3.2 Flexibility Methodologies

2.3.2.1 Design for Manufacturability

Design for manufacturability (DFM) is an approach to design and development that considers in its process the manufacturing attributes and capabilities available. DFM aims to ensure that new products are compatible with the existing manufacturing system and thus are economically viable to produce.

DFM concerns the use of a range of techniques in product design such as (1) limiting the number of production parts, (2) encouraging modular assembly, (3) eliminating assembly adjustments and (4) specifying standard parts (Noaker, 1992). The application of these techniques depends on the integration between process design, process planning and fixtures planning (Ong and Nee, 1996).

The major benefit of DFM methods is on reducing costs such as with materials and assembling. They also increase the product's reliability and minimise inventories and development cycle times (Venkatachalan, 1992). Mix and process flexibility increase due to lower parts variety in the system (Gerwin, 1987; Chen, Calantone and Chung, 1992). According to Youssef (1994), DFM increases product flexibility by speeding the response to customer's changing needs. The successful implementation of DFM requires effective team work practices and the integration process suggested above.

2.3.2.2 Group Technology and Cellular Manufacturing

Group Technology (GT) principles and their application into manufacturing cells design are a traditional source of flexibility. GT reorganises system's elements such as parts, machines and activities according to their characteristics or similarities. It simplifies the management of variety so that one may increase flexibility at affordable costs (Wiley, 1986).

One may apply GT principles into other design and manufacturing activities as well. In product design, GT usually concerns the implementation of classification and codification systems that help in building parts data bases. This increases design speed, productivity and quality and the product flexibility response (Gilbert and Winter, 1986).

The application of GT methods to manufacturing cells design has benefits such as lowering lead time and work-in-process, increasing capacity and dependability levels and simplifying the production planning and control (Meredith, 1987a; Gilbert and Winter, 1986). It also leads to increasing flexibility types such as product, volume and expansion (Browne et al., 1984; Frazelle, 1986; Sethi and Sethi, 1988).

2.3.2.3 Set-up Times Reduction

Set-up times reduction is one of the most effective ways of increasing flexibility types such as product, mix, machine, process and production (Sethi and Sethi, 1988; Browne et al., 1984; Monden, 1990). Set-up times may improve with new technologies or organisational procedures. Shigeo Shingo defined the major standard procedure in this area (Monden, 1990). This is called SMED System (Single Minute Exchange Dye) and suggests that set-ups of typical manufacturing operations could take less than one minute. The SMED system is a sequence of activities, or principles, that lead to severe reductions in set-up times, such as (Monden, 1990; Schmenner, 1990):

- Distinguishing between 'external' and 'internal' preparations. One should make external preparations while the machine is operating;
- Eliminating adjustments, using devices or specifications to contrast a tool from others;
- Emphasising the training and practice of set-up to enhance its accuracy and speed.

The major benefits of set-up reduction are in flexibility. They concern also operations cost reduction, increasing process quality and reliability, increasing capacity and reducing lead-times.

2.3.2.4 Human Resources Policies

The development of labour flexibility may relate to a broad range of personnel policies. These policies concern usually modern practices in human resources management such as low supervision, team working and multi-skilled workers. The development of such practices is essential to labour flexibility as they entitle the workforce to rent the benefits of other flexibility technologies and methodologies.

The major human resources policies that lead to labour flexibility are: (Correa, 1992; Saraph and Sebastian, 1992; Sykes, Simpson and Shipley, 1995):

- Job rotation;
- Training for flexibility, including another skills and functions;
- Wage system rewarding flexibility;
- The development of team work practices;
- The redefinition/expansion of job designs;
- The redefinition of the role of supervision.

Besides the development of labour flexibility, these practices may support the improvement of other flexibility types and MSDs.

2.3.2.5 System's Management Policies

Besides these technologies and methodologies, some authors suggest increasing flexibility performance through better management practices. These practices concern improving activities such as, for example, production scheduling and capacity management.

According to Gerwin (1993) and Sethi and Sethi (1988), increasing the system's capacity increases its product and volume flexibility. Increasing capacity limits may follow 'internal' practices such as the acquisition of spare or oversized facilities or 'external' practices such as subcontracting (Van Dijk, 1995). Rerouting flexibility may increase with duplicated operation assignments or the use of redundant equipment (Browne et al., 1984; Gerwin, 1993).

In spite of their impact on flexibility, increasing capacity and redundant equipment should be made with criteria. They may also increase production costs and lead times and decrease the system's reliability. This is a common trade-off of flexibility performance.

2.4 Flexibility Measurement

This section discusses the measurement of flexibility performance. The first part discusses the different types of flexibility performance: required, potential and actual flexibility. The second part reviews the literature on flexibility measures relating to the different flexibility types discussed in Section 2.2.1.

2.4.1 Required, Potential and Actual Flexibility

Measuring the performance of any MSD may involve different approaches. The literature has been specially concerned with defining and comparing these approaches in the context of flexibility, probably because of the inherent difficulties of its assessment. This literature defined three major types of flexibility performance: required, potential and actual flexibility. Each type has different implications and requires different management actions. Moreover, differences between measures in different approaches may highlight specific problems in manufacturing management, as following discussed.

Required flexibility is the level of flexibility performance demanded by the external and internal environments (Gerwin, 1993). This is how good the system should be. The assessment of required flexibility usually follows managers or specialists estimations of present and future market requirements.

Potential flexibility is the number of options that the system may assume (Gerwin, 1993). Pyoun and Choi (1994) defined this as the inherent flexibility of a system before its running. According to Slack (1983), the assessment of potential flexibility should also rely on personnel estimations, since measures in the shop-floor would have little significance.

Concerning the performance of machines, Pyoun and Choi (1994) suggest the use of manuals or the equipment suppliers as sources of additional information.

Actual flexibility is the measure of the system's effective performance (Gerwin, 1993; Pyoun and Choi, 1994). It is the amount of potential flexibility effectively used. One may assess the actual performance with 'concrete' data from the shop floor, using historical series or other objective procedures (Dixon, 1992).

It is important to stress that the performance measures for required, potential and actual flexibility can and should be the same to allow comparisons among these. What changes is their sources, which may be of subjective or objective nature.

Some authors discussed the appropriateness of such subjective, perceptual measurement of required and potential flexibility. Dess and Robinson (1984) suggested that there is usually a strong consistency between subjective and objective measures. According to Gerwin (1987), the evaluation of experts is appropriate when it is not feasible using objective information to assess flexibility. Aaker and Mascarenhas (1984) and Cox (1989) stated that subjective measures are always necessary to address flexibility in a system's context. Slack (1983) stressed that perceptual measures are the most adequate to assess the required and potential flexibility.

The analysis of differences between the required, potential and actual flexibility may suggest investments priorities and point out problems or failures in the system's design or operation. Differences between required and potential performance relate usually to design failures. Differences between potential and actual performance relate usually to operations failures. Gerwin (1993) discussed some sources of these differences as following:

a) Required flexibility greater than potential:

- There may be no technologies providing the flexibility that humans provide. At its beginning, the implementation of AMTs in labour-intensive plants is likely to produce mixed results, such as increasing some flexibility types and decreasing others;
- When designing AMT's, one may focus on objectives that are 'easier' than flexibility, such as quality and productivity. Failures in recognising trade-offs

between flexibility and other objectives may lead to unexpected reductions in flexibility potential levels.

b) Potential flexibility greater than required:

- There may be pressures from OM or other departments for acquiring equipment that provides more flexibility than it is necessary.

c) Potential flexibility greater than actual:

- Poor management, unable to 'use' all the potential flexibility;
- Emphasis in other performance objectives such as cost reduction, instead of flexibility capabilities such as set-ups and production planning.

Gerwin (1993) suggested some actions to avoid such discrepancies. First, the firm may use alternative flexibility sources. Second, trade-offs between flexibility and other objectives should be properly considered. Third, OM should assess the option between flexibility and focus (or other reduction strategies).

2.4.2 Flexibility Measures

Three major reasons justify the use of flexibility measures. First, researchers need to investigate flexibility and test hypotheses on its impact on manufacturing (Dixon, 1992; Gerwin, 1993). Second, OM needs to evaluate the system's performance by comparing the flexibility of different units, companies or time periods (Gerwin, 1987; Dixon, 1992). Third, strategy managers need to compare market needs with the system's potential and actual performance (Slack, 1988; Aaker and Mascarenhas, 1984). These are the theoretical, operational and strategic justifications for the use of flexibility measures.

Concerning the objectives of this study, one should consider some points before the presentation of flexibility measures. First, it is necessary to distinguish between the 'economic evaluation' and the 'performance assessment' of flexibility. The first is the evaluation of the economic viability of new investments, specially those involving new technologies. The second relates to the management of flexibility. These approaches require different types of measures. The first requires cost measures, while the second requires operational measures, usually expressed within time or rates[4]. This study relates to the second approach and thus reviews operational measures. Recent studies concerning the economical evaluation of flexibility are Fine and Freund (1990), Kulatilaka and Marks (1988), Boyer (1992), Lint (1992), Pyoun and Choi (1994) and Azzone and Bertele (1989).

Second, to allow comparisons, the same measures must apply to the required, potential and actual performance types. The only change here is on the sources of these measures. This was discussed above.

Third, the range and response dimensions developed by Slack (1983) and discussed in Section 2.2.3 may describe the flexibility performance. The 'range and response' curves used by Slack and Correa (1992) may be used here.

Finally, the literature provides several examples of disagregated measures (related to some flexibility types) and some examples of aggregated measures (related to the whole system's flexibility). Slack (1983) suggested that the existence of so many flexibility dimensions, types and approaches turns the measurement of aggregate flexibility difficult in practice. According to Barad and Sipper (1988), the complexity of the set of decisions that influence the flexibility performance turns such task impossible. Some authors suggested some aggregate measures (Zelenovic, 1982; Ramsesh and Jaikumar, 1991; Jordan and Graves, 1991). They provided examples but not empirical tests of these measures. Given this context and the objectives of this study, this review focuses on disagregated measures only.

Gupta and Goyal (1989) classified flexibility measures along six categories: economic, aggregated and multi-dimensional measures, discussed above, and the less common Petri-nets, information theoretical and decision theoretical measures. Petri-nets are the most used among these later categories. Barad and Sipper (1988) used Petri-nets as an aggregate measure, modelling the production system in a structure of events and conditions and evaluating its flexibility by developing an initial scenario and introducing changes (noise) with which the system has to cope. The major problem of Petri-nets is their difficulty to

[4] Bernardo and Mohamed (1992) disqualified the use of cost measures in the flexibility performance assessment, since a firm's cost structure usually changes over time. This would require constant adjustments when assessing the flexibility of different periods, turning instruments such as time series unreliable.

model complex systems and to assess the impact of flexibility beyond the operational level (Gupta and Goyal, 1989; Barad and Sipper, 1988).

Type/Approach	Flexibility Performance Measures
Product Range, dynamic	Number of new products in a given time/total number of products (Dixon 1992) Number of parts that can be introduced in a year (Bernardo and Mohamed 1992) * Number of design changes in a component/time period (modification) (Gerwin, 1987)
Range, static	Number of product codes in a given period (Bartezzaghi and Turco 1989) Number of parts made by year (Jaikumar, 1984) Range of products the company has the ability to produce (Slack and Correa, 1992)
Response	Time between order for a sample and its shipment (Dixon 1992) Time and cost of new product introduction (Bartezzaghi and Turco, 1989; Dixon, 1992; Gupta and Goyal, 1989; Slack and Correa, 1992) *
Mix Range, dynamic	The range of products the company may produce in a given period (Slack and Correa, 1992; Dixon, 1992; Bartezzaghi and Turco, 1989) Average number of changeovers between those characteristics (Dixon 1992)
Range, static	Average number of different product characteristics made simultaneously (Dixon 1992) Range of diversity the system is capable of handling at one time (Bernardo and Mohamed, 1992)
Response	Time necessary to change the mix of products being manufactured (Slack and Correa, 1992)
Delivery - Range	The extent to which delivery dates can be brought forward (Slack and Correa, 1992)
Response	Time to reschedule the manufacturing system for the new delivery date (Slack and Correa, 1992)
Production Range, dynamic	Number of component substitutions in a given period, corrected by the degree of difference between components (Gerwin, 1987) Number of part types the system can produce without major set-ups (Sethi and Sethi, 1988) * Number of parts the system may produce (Sethi and Sethi, 1988; Gerwin, 1987) *
Range, static	Number of parts that can be simultaneously processed without batches (Chen and Adam, 1991)
Response	Set-up times (Gupta and Goyal, 1989; Wernecke and Steinhilper, 1982)
Volume Range, static	The smallest production volume to sustain profits (Chen and Adam, 1991; Browne et al., 1984) * The absolute level of aggregated output that the company can achieve for a given product mix (Slack and Correa, 1992) *
Range, dynamic	Average volume fluctuations in a given period/capacity limit (Gerwin, 1987)
Response	Time taken to change the aggregated level of output (Slack and Correa, 1992)
Expansion Range	Upper limit on the amount of capacity expansion (Browne et al., 1984; Chen and Adam, 1991) Minimum percentage increase in capacity (Bartezzaghi and Turco 1989)
Response	Time and costs to convert to new production levels (Bartezzaghi and Turco 1989; Carter, 1986) *
Process Range	Number of different process plans for a part (Sethi and Sethi, 1988; Chen and Adam, 1991) Extent of variations in key material properties handled by the equipment (Gerwin, 1987) Total throughput/waiting costs of parts processed (Son and Park, 1987) *
Programming Range/response	Expected percentage uptime during second and third shifts (Jaikumar, 1984) *
Rerouting Range (parts)	Average number of ways (routes) in which a product can be made (Chung and Chen, 1989; Bernardo and Mohamed, 1992; Chatterjee et al., 1984)
Range (system)	Existing paths/total possible paths (Carter, 1986; Primrose and Leonard, 1984; Kumar, 1987) *
Response	Drop in production when a machine stoppage occurs (Buzzacott, 1982; Chen and Adam, 1991) * Ratio of expected production (when some machines are not working)/production of the fully operating system (Gupta and Goyal, 1989; Kumar, 1987)
Machine Range	Number of different operations performed by the machines weighted by the importance of tasks (Brill and Mandelbaum, 1987; Gerwin, 1987) Extent of variation in the inputs that the machine can handle (Gerwin, 1987) Number of operations it may perform within a certain cost or time (Sethi and Sethi, 1988) * Number of components made by the equipment/total number of components (Buzzacott, 1982)
Response	Time to change tools to produce a different subset of part types (Chen and Adam, 1991) Set-up time/process time (Falkner, 1986) Cost of switching from one operation to another (Sethi and Sethi, 1988)
Labour - Range	Number of tasks performed in average by the workers (Atkinson, 1985)
Response	Readiness with which the number of workers can be changed (Atkinson, 1985)

Table 2-6: A summary of flexibility performance measures.

Table 2-6 reviews a number of flexibility measurement parameters that may be useful for this study's collection and analysis of data. Gupta and Somers (1992) made a survey of the technical validity of 34 of these measures and selected 21 as appropriate in practice. Measures among these 21 measures are indicated by a '*' in the table.

2.5 Flexibility and Manufacturing Strategy

The study of manufacturing flexibility relates to different disciplines such as economics, management and industrial sociology. MS studies usually focus on subjects concerning the strategic scope of flexibility and not as related to other disciplines. The main aspects of the study of flexibility in MS are following discussed.

The first aspect is the link between flexibility planning and MS planning. The system's flexibility has to be consistent with competitive needs. According to Chambers (1990), one should define flexibility needs along the MS planning. He proposed the use of Hill's (1985) framework on MS planning (Section 1.2) for the identification of flexibility requirements and programs. Elango and Meinhart (1994) developed a framework for the analysis and selection of FMS in the context of MS. This framework considers (a) industry and market needs, (b) the strategy of the firm and (c) organisational capabilities needs. These are later translated into flexibility needs and then into appropriate FMS technologies.

Second, some studies assessed the role of flexibility in competitiveness. According to Fensterseifer (1992), increasing flexibility increases the firm's portfolio of strategic options and creates uncertainty to its competitors. Flexibility is essential to the development and sustaining of major manufacturing strategies (Hayes and Wheelright, 1984; Correa, 1992). Chen, Calantone and Chung (1992) provided cases of firms that used flexibility to support competitive strategies such as increasing product diversity (Honda), shortening product life cycles (Compaq) and (dealing with) increasing buyer concentration (Volvo Components).

Third, Oktemgil (1994) developed a framework that matches flexibility with generic competitive strategies. This idea could be extended to the linking between flexibility types and generic manufacturing strategies types such as discussed in section 1.1.2.

Finally, Ward et al. (1995) suggested that the apparent lack of studies linking MS and flexibility may relate to the shortage of empirical MS studies that include a treatment of environmental factors. Moreover, there is a lack of studies concerning the integration of the different 'flexibility theories' developed within disciplines such as economics, management, engineering and sociology. As Genus and Dickson (1995) stated, the 'farewell to flexibility' bid of some studies may be precipitated.

2.6 Chapter Conclusions

This chapter discussed five major subjects on manufacturing flexibility that are (1) the flexibility concept, (2) the manufacturing flexibility theory, (3) sources of flexibility, (4) flexibility measurement and (5) the relationship between flexibility and MS. Each subject has different implications in this study as well as in the literature.

The building of a concept for flexibility in the context of OM used to be a major subject in the literature. However, as there seems now to be an agreement on this issue, the debate has moved to other questions. The formulation of a concept of manufacturing flexibility is essential to the collection and analysis of flexibility data in the investigation. The concept defined in the first section is the one to be used in the field work.

The definition of major aspects of a flexibility theory such as dimensions, types and levels characterise also earlier studies. Among these aspects, the flexibility types and levels have special importance in the research framework. One can only understand a firm's current and required flexibility if one understands the characteristics and the relationships of its different variables within the firm.

Flexibility technologies and methodologies are a major issue in the present literature. Since these are constantly changing, their understanding and insertion as part of a MS is a major challenge. Moreover, aspects of their implementation are also an important subject in the OM literature. The understanding of flexibility technologies and methodologies is essential to this study's objectives and framework, to lead to the establishment of relationships between flexibility resources, capabilities and trade-offs.

Finally, the development and testing of flexibility measures seem to be also an important subject in the literature. It is fundamental that people understand the strengths and limits of these measures, since flexibility has been usually referred as the 'worst measurable' manufacturing dimension. Thus the study of methods and practices for the assessment of flexibility seems to be as important as their definition. This study concentrates primarily on perceptual measures of flexibility. However, quantitative measures will be applied if necessary to understand the flexibility of the case companies.

This review suggests some questions that may be open for further investigation in this and in subsequent studies. The questions on the scope of flexibility are the following:

1. There seems to be a major difference between the approach of the 'flexibility' literature as in this chapter and Chapter 1's 'MS content' literature. Here, flexibility is considered a system's internal attribute, with an impact on a series of operations objectives. There, it is seem as an objective, comparable with others such as cost, quality and speed. One should investigate whether these two ideas are compatible and/or there is a difference between the concepts of 'internal' and 'external' flexibility;
2. One could investigate whether increasing specific flexibility types relies on developing specific flexibility capabilities and resources or just on applying these capabilities and resources to different situations. In other words, do different flexibility capabilities and resources have a specific, identifiable impact upon certain flexibility types (permitting the construction of frameworks of cause and effect)? If not, do these have a rather broad impact on the system and thus can be applied to different objectives and circumstances?
3. Finally, one has to define how one closes the gaps between a system's required and potential performance and between its potential and actual performance. Closing these gap areas may require different approaches in MS formulation and implementation. Furthermore, one should identify what is the relationship between these gaps and a system's trade-offs.

Chapter 3 - Manufacturing Trade-offs

Chapter 3

Manufacturing Trade-offs

Introduction

Manufacturing trade-offs are compromises between different production objectives or variables. They were first defined as such in the earliest MS studies. These studies viewed trade-offs as deterministic and static constraints to the MS. Such view was challenged in the 80's, as some studies demonstrated that different manufacturing objectives might in fact enhance - instead of diminish - each other's performance. These studies suggested that manufacturing trade-offs do not exist. However, the idea of production systems with no performance limits has never been all accepted. Later studies suggested that trade-offs still exist but they are contingent and dynamic.

This chapter reviews the literature on manufacturing trade-offs. Section 3.1 presents the classical concept of trade-offs. Section 3.2 discusses the different views on the nature of trade-offs in OM. Section 3.3 reviews the characteristics of the relationships between the five MSDs presented in Chapter 1.

3.1 The Concept of Trade-offs

A trade-off is a compromise between two or more variables (Skinner, 1969). The existence of a trade-off between two variables means that improving the first variable's performance has a negative impact on the second's performance. In OM, trade-offs are usually assessed when deciding upon alternative objectives or actions on the system's design (Miller, 1983; Skinner, 1969) or modification (Stobaugh and Telesio, 1983; Banks and Wheelright, 1979).

Managing a trade-off is deciding upon alternative options that have distinct impacts on its variables. Along this classical view of trade-offs, one may decide basically whether to (1) minimise the cost of one variable at the other's expense or (2) minimise the combined cost of both variables (Figure 3-1).

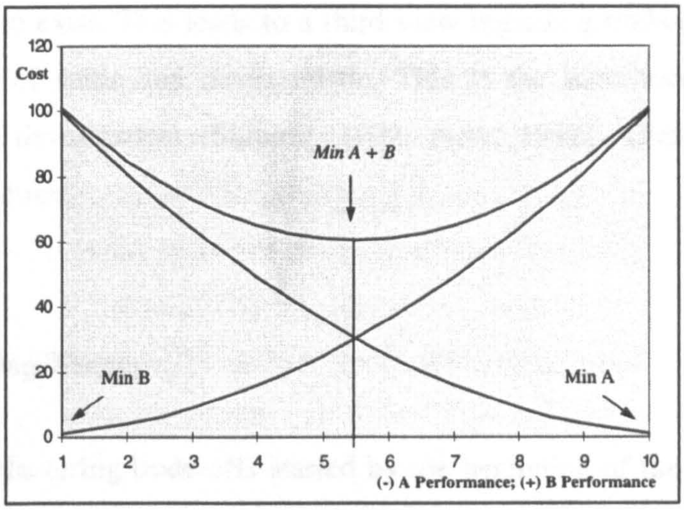

Figure 3-1: A Trade-off Between Two Variables

The assessment and management of trade-offs is perhaps one of the most important tasks in today's OM. Modern strategies such as focused factories, lean manufacturing and agile manufacturing are all related to the improvement of well-defined trade-offs.

3.2 The Theory of Manufacturing Trade-offs

The debate on manufacturing trade-offs started within the earliest MS studies. Skinner (1969) proposed that manufacturing systems do not compete only in cost but in other dimensions as well. OM should set priorities in manufacturing competitiveness. This approach characterised most early MS studies (Miller, 1983; Stobaugh and Telesio, 1983; Banks and Wheelright, 1979). It concerns what one may call the 'traditional' theory of trade-offs that dominated OM from the early 70's to the middle 80's.

The rising of new programmable technologies challenged this view (Schroeder et al., 1995). As these technologies appeared to improve many performance objectives at the same time, a deterministic view of trade-offs seemed no longer valid (Schonberger, 1986;

Collins and Schmenner, 1993; Corbett and Van Wassenhowe, 1993). A 'World Class Manufacturing' (WCM) approach appeared in the late 80's suggesting the end of trade-offs.

However, the WCM view has been also criticised (Skinner, 1992; New, 1992; Slack, 1991; Hayes and Pisano, 1994). Since economic resources are ever limited, manufacturing trade-offs can not cease to exist. This leads to a third view regarding trade-offs as *dynamic* and *contingent* instead of static and deterministic. This is the most recent theory and still requires extensive development (Skinner, 1992; New, 1992). These ideas are further discussed in this section.

3.2.1 The Founding Theory

The study of manufacturing trade-offs started by the beginning of the 70's. These studies viewed trade-offs as contingent and deterministic. That is improvements in one trade-off variable always decrease the other variable's performance. OM could not improve many performance objectives simultaneously unless the system was operating with slack.

Skinner (1969) was the first to study trade-offs under a MS perspective. He suggested that the failure of OM on defining performance priorities was in fact a failure on understanding the trade-offs in their systems. Each production system has potential trade-offs between alternative design and performance options.

Following studies applied Skinner's ideas to understand the choices relating to a series of trade-offs on performance priorities. These studies focused on trade-offs such as between variety and cost (Miller, 1981; Hayes and Wheelright, 1979a, Banks and Wheelright, 1979), quality and cost (Skinner, 1974; Miller, 1981; Hayes and Wheelright, 1979a, Stobaugh and Telesio, 1983) and delivery speed and inventory cost (Skinner, 1974; Miller, 1981). Cost was still the major performance priority in manufacturing.

This first approach was based on three major ideas. **First**, a production system can not satisfy simultaneously every performance objective. Technical constraints limit the range of abilities that one may develop (Skinner, 1969; 1974). Miller (1981) called these constraints the 'design limits of the plant'. **Second,** since there are limits for what a system can do, OM should set performance priorities - the 'plant mission'. These priorities should follow the competitive strategy (Miller, 1981; Skinner, 1974; Hayes and Wheelright, 1979a). **Third,** the system's design should follow these priorities. Plants should focus on a limited and well-defined set of performance objectives. (Skinner, 1974; Hayes and Wheelright, 1979a).

This theory's parallel in the business strategy literature is Porter's (1985) 'generic strategies'. Porter proposed that a firm can only achieve competitive advantage when competing along one out of two alternative strategies that are the *cost leadership* strategy and the *product differentiation* strategy. Hall's (1980) case studies reinforce this view. He suggested that successful companies are in either the lowest cost or most differentiated position in the industry. Stobaugh and Telesio's study (1983) on manufacturing policies and product strategy also follows this view. Porter's approach was later challenged, just as it happened in the MS literature.

3.2.2 World Class Manufacturing

The World Class Manufacturing idea appeared first by 1986. It has been defined by Schonberger (1986) and was later endorsed in studies such as Collins and Schmenner (1993), Fry, Steele and Saladin (1994) and Corbett and Van Wassenhowe (1993).

According to Schonberger (1986), MSDs such as cost, quality and speed are not opposed. If OM follows some simple rules, different performance objectives may be 'pursued in concert'. This view defies former MS prescriptions such as 'set your competitive priorities'. As Collins and Schmenner stated (1993: 446), "The view of manufacturing as structurally unable to 'be all things to all people' is now obsolete and should be forever abandoned". A World Class Manufacturer is able to deliver products at high competitive standards of quality, cost, dependability and speed (Fry, Steele and Saladin, 1994).

The WCM view thus suggests that trade-offs do not exist. Schonberger (1986) suggested the fall of the 'trade-off myth'. The idea of trade-offs was a mistake disseminated by 'a few generations of MBAs'. The best manufactures are likely to be good in all areas. Collins and

Schmenner (1993) proposed the abandonment of 'trade-offs' in favour of 'complements'. Ferdows and De Meyer (1990) suggested 'enhancements' in place of 'trade-offs'.

World Class Manufacturing strategies are based on simplicity and discipline in manufacturing (Collins and Schmenner, 1993). According to Fry, Steele and Saladin (1994) one may develop WCM through measures such as inventories reduction. Schonberger summarised this appeal suggesting that WCM characteristics such as simplicity, overwhelming logic, quick and visible results, low cost and personal excitement guarantee its attainability. WCM is easy to attain. It is not an 'idealist's dream'.

The WCM view has some major weaknesses, though. The belief that production systems may achieve everything assumes that this is a world of unlimited resources. WCM is based on the idea that what many companies achieved in recent years undermines the idea of static and deterministic trade-offs. However, WCM studies failed to identify the reasons behind this apparently revolutionary finding. Their faltering simplicity and lack of empirical evidence have been criticised in later studies (New, 1992; Skinner, 1992). Instead of revising and improving the trade-offs theory, WCM studies simply disregarded it.

3.2.3 The Dynamics Theory

The apparent failure of WCM studies to explain the changes in the nature of industrial competition suggested the need for a new approach. This has been developed from the beginning of the 90's by studies such as Skinner (1992), New (1992), Slack et al. (1995) and Hayes and Pisano (1994).

The major idea in these studies is the following. The range of abilities, design features and technologies employed in a production system limit its performance. However, this relationship is dynamic. Changing this range of abilities, features or technologies should change the performance limits - and therefore the trade-offs - of this system. That means changing the system may change the nature of its trade-offs (Skinner, 1992).

This was evident with the rising of programmable technologies (Schroeder et al., 1995; Ferdows and Skinner, 1987). Since these technologies high flexibility[1], the principles of the relationship between variety and cost were the first to be revised (Goldhar and Jelinek, 1983; Meredith, 1987b; Blois, 1985). The combination of these technologies with other strategies challenged trade-offs such as speed and dependability, quality and cost and speed and flexibility (New, 1992).

This leads to this theory's first proposition: *trade-offs are dynamic* (Skinner, 1992). The major benefit of new technologies is their effect on changing the nature of trade-offs. Flexibility and quality are not free, but cheaper than ever. This is the major difference between this and the former approaches. The idea is, if one develops new resources and abilities properly, conflicting objectives could be improved simultaneously (Corbett and Van Wassenhowe, 1993; Ferdows and De Meyer, 1990).

Slack (1991) suggested that the major impact of advanced technologies and methodologies is on raising the trade-offs 'pivots' (Figure 3-2). If setting priorities is still appropriate in the short term, long-term competitiveness requires real system's improvements. Hayes and Pisano (1995) suggested the idea of 'improvement trajectories' to stress a similar idea.

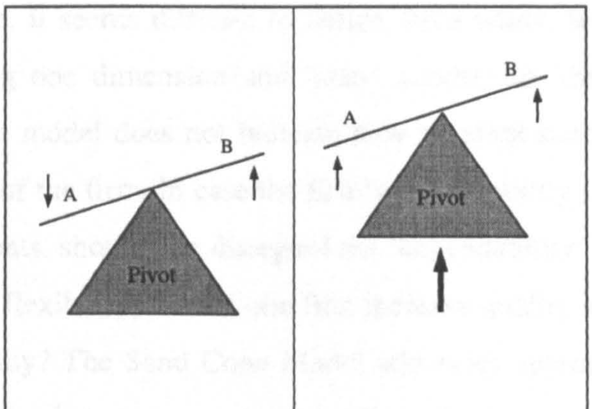

Figure 3-2: Short and long term trade-offs management
Source: Slack, 1991.

The idea that trade-offs depend on the range of technologies and abilities available leads to this theory's second proposition: *trade-offs are contingent*. The nature of a system's trade-

[1] Here, 'high' mean a large amount of both range and response flexibility. That is the flexibility provided by programmable technologies is cheaper than that provided by rigid technologies.

offs depends on the abilities and resources available and on their integration (Filippini, Forza and Vinelli, 1995; Slack, 1991). For example, the trade-off between quality and speed depends on abilities such as set-up costs. That is OM should not select upon performance objectives but instead upon trade-offs to improve (Hayes and Pisano, 1994; Spring, 1995). This was noted in Wheelright's (1981) study on the practices of Japanese companies. Instead of setting performance priorities, those companies selected the practices that had greater impact on the overall performance. His example on quality versus cost may be extended to other trade-offs.

This idea reflected in Ferdows and De Meyer's (1990) 'Sand Cone Model'. This model suggests that the occurrence of trade-offs depends on the sequence by which one develops different MSDs. The authors proposed a 'best sequence' for developing MSDs that is (1) quality, (2) dependability, (3) flexibility and (4) cost. Following this sequence, one eliminates the occurrence of trade-offs. The authors assumed that trade-offs operate in one direction only (e.g. cost undermines quality but quality does not undermine cost) and thus OM should focus first on MSDs whose performance may be undermined by others.

The major problem with this model is the absence of empirical evidence so far for its corroboration in practice[2]. Even the data provided in that study could not provide such evidence. Furthermore, it seems difficult to define from which level of performance one may 'stop' developing one dimension and 'start' another (in the following step of the sequence). Finally, the model does not indicate how to adapt such sequence to the actual competitive priorities of the firm. In case the firm's dependability performance exceeds the competitive requirements, should one disregard the 'dependability' step? In case there is an urgent need for better flexibility, should one first increase quality and dependability before proceeding on flexibility? The Sand Cone Model addresses appropriately the contingency of trade-offs relationships but seems not to be itself contingent.

Concerning the business strategy literature[3], Porter's (1985) trade-off of cost versus differentiation strategies has also been criticised. Some authors proposed that these

[2] Noble (1995) tested a revised Sand Cone Model and could only provide evidence for the simultaneous improvement of different MSDs but not for the validity of a 'sequence' of implementation.

[3] This paragraph reviews propositions from the business strategy literature concerning both the second (WCM) and third (dynamics) approaches.

strategies are not always incompatible. Miller and Dess (1993) stated that combining these strategies is possible and profitable. According to Murray (1988), this combination is possible because the factors of success of a cost strategy (the industry's structural characteristics) are independent from those of a differentiation strategy (customer tastes). Cranshaw, Davis and Kay (1994) provided the example of Sainsbury's in the UK as a company able to profit in a mid-market position. Jones and Butler (1988) stated that these strategies may be either incompatible or not, depending on their cost and revenue dynamics. They suggested that Porter's trade-off depends on structural and infra-structural factors.

The dynamic approach seems to be the most appropriate in today's OM context. First, as Slack (1991) pointed out, this theory is improvement-oriented. It highlights the prospect of improving trade-offs. Second, the idea of contingency (trade-offs relate to a number of structural and infra-structural factors) agrees with the recent resource-based approach in MS. Third, these ideas focus on the causes instead of the effects of trade-offs in production systems. Nevertheless, these ideas are still recent and demand some extensive theoretical and empirical development (Skinner, 1992; New, 1992).

3.2.4 Section Conclusions

Section 3.2 reviewed the major ideas about trade-offs as in the MS and business strategy literature. One may identify three major approaches in both disciplines. Table 3-1 summarises the major studies in this review relating to each approach.

Research Approach	MS Sources	BS Sources
Static, deterministic trade-offs	Skinner (1969); Hayes and Wheelright (1979a)	Porter (1985)
Trade-offs do not exist	Schonberger (1986)	Murray (1988); Miller and Dess (1993)
Dynamic, contingent trade-offs	Skinner (1992); New (1992)	Jones and Butler (1988)

Table 3-1: Manufacturing and business strategy trade-off's approaches

The dynamic approach may be interpreted as the present stage in MS. It is the latest stage of an evolutionary process that started more than 20 years ago. Table 3-2 suggests how MS might have developed through these ideas. It shows the impact of major empirical and theoretical studies on revising old ideas and suggesting new MS policies.

Research Stage	From Static to Dynamic Trade-offs	From Deterministic to Contingent Trade-offs
1. Former policy	Design operations system towards specific objectives (Skinner, 1974; Hayes and Wheelright, 1979a)	Focus on competitive priorities (Skinner, 1974; Miller, 1981)
2. Empirical findings	The effects of flexible technologies (Goldhar and Jelinek, 1983; Blois, 1985; Meredith, 1987a)	The Japanese practices (Wheelright, 1981)
3. Theories and models	New technologies and trade-offs (New, 1992; Skinner, 1992)	Sand Cone Model (Ferdows and De Meyer, 1990)
4. New policy	Continuous improvements (Slack, 1991; Hayes and Pisano, 1995)	Select trade-offs to improve (Hayes and Pisano, 1994)

Table 3-2: The evolution of a manufacturing trade-offs theory

According to this summary, the appearance of flexible technologies challenged assumptions such as of scale economies and static trade-offs. The major effect of such technologies was improving the relationship between variety and cost, leading to the idea of scope economies (Goldhar and Jelinek, 1983; Blois, 1985; Meredith, 1987a).

Following studies demonstrated that other trade-offs could be also improved. The effects of new technologies and methodologies extend to all MSDs. New technologies and methodologies affect not individual dimensions but rather multiple trade-offs. New (1992) revised the nature of trade-offs such as quality and cost, speed and quality and flexibility and speed. Skinner (1992) developed a model to explain such impact. From now on, trade-offs are seen as dynamic.

The dynamic view of trade-offs reinforces the need for continuous improvements to maintain the long term competitiveness of manufacturing. This is now corroborated by the idea of trade-offs pivots and the possibility of improving trade-offs (Slack, 1991). *Defining the meaning of trade-offs pivots is one of the objectives of this research.*

The second development was from deterministic to contingent trade-offs. Wheelright (1981) suggested that Japanese companies selected different manufacturing policies first upon their impact on performance and second upon their relationship with the competitive strategy. Different policies have different impacts depending on the importance and performance of trade-offs that characterise a company.

Ferdows and De Meyer's (1990) Sand Cone Model follows this approach. The authors suggested that the apparent differences upon the impact of specific policies are due to prior characteristics of the system. Trade-offs operate in one direction only and thus there is a best sequence for the development of MSDs.

The Sand Cone Model and Wheelright's study suggest that trade-offs are contingent. That is their strength and importance depend on structure and infra-structure factors. OM should concern improving major trade-offs rather than adapting the strategy to the systems' strengths and weaknesses (Hayes and Pisano, 1994). *The study of how to manage trade-offs is another objective of this research.*

3.3 Manufacturing Objectives Trade-offs

Section 3.3 reviews the literature on the relationships between the five MSDs presented in Chapter 1: cost, quality, flexibility, speed and dependability. Each sub-section analyses the relationship of a single pair of dimensions.

3.3.1 Flexibility and Cost

An important issue in the analysis of the relationship between flexibility and cost (and indeed between flexibility and any other MSD) seems to be the conceptual distinction upon flexibility and variety. First, while variety is expressed by absolute measures, flexibility is a multi-dimensional concept that includes cost in its formation. Flexibility is the ability to assume a range of states at a determined cost and time response. It may be expressed as [variety / (cost x time)], that is (range/response).

Cost is part of the concept and measure of flexibility. It reflects the responsiveness of flexibility capabilities such as set-ups, product development and parts routing. Flexibility and operations cost are thus inter-dependent. If flexibility is variety/cost, the only way of increasing the flexibility for a *fixed* range of parts is reducing changing costs.

The study of trade-offs between flexibility and cost should focus on the impact of flexibility on *fixed* cost. In contrast to operations cost, fixed cost has no part in the flexibility concept. They are external to flexibility as their performance is affected by rather than dependent on flexibility.

This topic thus consists of two parts. The first concerns the relationship between variety and operations cost. The second concerns flexibility versus fixed cost[4].

Yeh and Chu (1991) investigated the impact of increasing variety in some operations cost types. They suggested that increasing variety increases costs such as work-in-process, inventories, set-ups and transportation. This impact is stronger in continuous systems.

The emergence of programmable technologies has challenged this trade-off (Schroeder et al., 1995; Nemetz and Fry, 1988; Blois, 1985; De Meyer et al., 1989; Goldhar and Jelinek, 1990). These technologies have the ability of cheaply switching from one task to another, leading to lower flexibility costs and the economic production of smaller batches. Learning curves are also shortened as 'smart' machinery may perform new tasks by following programmed instructions (Talaysum, Masson and Goldgar, 1987). These technologies rely on economies of scope since their major source of productivity is on increasing variety instead of volume[5] (Goldhar and Jelinek, 1983).

According to Upton (1995), the successful implementation of these technologies relies on their appropriate combination with labour abilities. These technologies are not panaceas. Their use as a cheap replacement of workforce may lead to failures such as those that characterised rigid technologies in the 70's.

Talaysum, Masson and Goldgar (1987) and Nemetz and Fry (1988) stressed some of the characteristics of flexible technologies that improve the relationship of variety versus cost:

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[4] Following topics also make specific references to variety and flexibility.

[5] It seems inappropriate suggesting that these technologies rely on scope economies *instead of* scale economies. They rather equal increasing variety with increasing volume. When set-up costs are zero, increasing variety is the same as increasing volume.

- The information already built into the software for an old variety may be used for a new variety, lowering design costs;
- As machinery and other facilities are able to work with a high variety of parts, parts from one line may be processed by another if necessary;
- With the ability to adapt to a higher number of circumstances, variations in inputs characteristics are more easily tolerated. The system is able to operate with a higher variety of materials and process sequences.

On the other hand, the literature usually acknowledges a trade-off between *flexibility and fixed cost* (Gerwin, 1993; Schroeder et al., 1995). This follows the idea of economies of scale (Mills, 1990, Kekre and Srinivasan, 1990). The problem here is that investments in flexible technologies usually increase fixed costs such as with facilities and spare capacity.

Gerwin (1993) suggested that increasing volume flexibility requires investments in excess capacity and empty floor space. Gaimon and Singhal (1992) investigated whether flexibility benefits such as reduced changeover costs and earlier market entry might compensate such costs. According to New (1992), the trade-off between design flexibility and cost still exists because unique customisation is always expensive to produce[6]. One should compensate increasing fixed cost with flexibility benefits such as increasing revenues - due to earlier market entry - or savings in areas such as breakdowns, set-ups and inventories.

The case of the Japanese car companies illustrates this trade-off. De Meyer et al. (1989) suggested that leading Japanese manufacturers were having problems to handle the increasing production complexities associated with flexibility strategies. According to Berggren (1993), Nissan attempted to reduce the number of variables in its models and to standardise as many parts as possible to cut costs and regain profitability. He says this practice seems to be widespread among Japanese car makers.

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[6] One may argue that the proposition of such trade-off is imperfect, as New (1992) compares different strategies (customisation and low cost). There is no problem here, though. If these strategies are different, this is exactly because their objectives are conflicting. If this argument is expanded, any trade-offs variables should be seem as part of different strategies. Actually, the degree to which one may distinguish objectives in a same strategy upon objectives in different strategies is not discrete but continuous. It is more appropriate to assess trade-offs independently from the competitive strategies they may relate.

- The literature points out a trade-off between variety and cost.
- Advanced technologies may improve this trade-off, but not to eliminate it.
- Increasing flexibility usually concerns lowering/changing variable costs.
- The literature points out a trade-off between flexibility and fixed costs.

3.3.2 Flexibility and Quality

The literature on the relationship between flexibility and quality is not very extensive. According to Gerwin (1993), these studies usually concern hypotheses of the impact of increasing flexibility on quality. This impact is considered negative, with some exceptions.

Gerwin (1987, 1989, 1993) suggested the following hypotheses on the impact of flexibility types on quality performance (rate of scrap parts):

- Increasing *product flexibility* increases the scrap rate. Quality reliability depends on rigid and specialised tooling which implicate low product flexibility;
- Increasing *volume flexibility* reduces the scrap rate. High volumes are usually processed at high speed and large batches, increasing the number of defects;
- Increasing *rerouting flexibility* increases the scrap rate. As more machines work on a same group of parts, differences along the specifications and wearing degrees of each machine turn it more difficult achieving high quality standards. As more alternative paths are created, efforts to eliminate machine breakdowns are also discouraged, reducing the process reliability;
- Increasing *materials flexibility* reduces the scrap rate. One may eliminate potential defects as machines can cope with inputs variations. However, this ability may discourage the actual elimination of such problems;
- Increasing *process (specification) flexibility* reduces the scrap rate. The ability to cope with process sequences variability helps to manage unexpected process variations and to maintain good quality standards.

Porteus (1986) study on the relationship between lot sizing, quality improvement and set-up cost reduction proposed that minimising lot sizes may increase the quality performance. Systems out of control tend to produce less defective units when working with small batches than with large batches. Increasing machine flexibility, by reducing set-up times, may reduce batch sizes and thus the rate of defective units. Porteus proposed that such 'hidden' quality benefits should be considered in the economic evaluation of flexibility.

Yeh and Chu (1991) analysed the impact of increasing product variety on some quality indicators. They suggested that increasing product variety increases quality problems such as rejecting incoming materials and producing defective units.

- Increasing operational flexibility types such as machine and rerouting increase the quality performance.
- Increasing strategic flexibility types such as product and volume decrease the quality performance.
- The literature points out a trade-off between parts variety and quality performance.

3.3.3 Flexibility and Speed

The literature points out a trade-off between parts variety and lead time (Yeh and Chu, 1991; Handfield and Pannesi, 1992; Crandall and Burwell, 1993). One can minimise this trade-off through modular production (New, 1992; McCutcheon, Raturi and Meredith, 1994; Daugherty and Pittman, 1995). Modular production is stocking standardised, partially finished products to be later adapted to incoming orders. Diversified orders may be thus delivered faster and with less disruption in the system. This strategy has two major problems, though. First, this differentiation is not true customisation and may be under required variety levels (New, 1992). Second, there is a risk that some of those 'basic products' may not meet corresponding orders in a valid period and will have to be reprocessed (McCutcheon, Raturi and Meredith, 1994)

Considering such problems, some authors proposed that true customisation and fast speed can only be achieved through increasing flexibility (Cordero, 1991; Handfield and Pannesi, 1992; Kumar and Motwani, 1995; Benjaafar et al., 1995). On Handfield and Pannesi (1992) study, five among thirteen companies indicated labour, machine and routing flexibility as major sources of increasing speed. These types provide the ability to cope with unexpected failures such as breakdowns, with no need to sacrifice variety or speed.

- The literature points out a trade-off between variety and speed.
- Operational flexibility types may improve the relationship between variety and speed.

3.3.4 Flexibility and Dependability

The impact of increasing flexibility on dependability is usually positive (Slack, 1991; Gerwin, 1989). First, it smoothes the impact of parts variety on dependability. Second, in spite of not *increasing* the dependability, it helps to minimise the impact of disruptions caused by dependability failures.

According to Yeh and Chu (1991), increasing variety has a negative impact on dependability. Broadening product lines increases the complexity of production planning and control activities (specially scheduling). Production plans change also more frequently as the number of part types increases and materials management becomes more complex. Such problems may threat the meeting of delivery schedules, and the overall reliability tends to decrease. Operational flexibility types such as machine, labour, routing and programming flexibility can minimise that impact of variety on dependability.

Increasing flexibility types such as rerouting, machine and labour minimise the impact of dependability faults, increasing the system's predictability and consistency (Gerwin, 1989; Slack, 1991; Benjaafar et al., 1995). For example, machine and rerouting flexibility permit re-routing jobs from disrupted areas to avoid delays.

Increasing dependability has a positive impact on flexibility. Dependability leads to more predictable systems, where fewer disruptions, break-downs and failures happen. This eliminates major sources of flexibility needs.

- The literature points out a trade-off between variety and dependability.
- Increasing flexibility improves the trade-off between variety and dependability.
- Operations flexibility minimises the impact of disruptions due to dependability faults.
- Increasing dependability minimises the need for flexibility.

3.3.5 Cost and Quality

The literature on the quality and cost trade-off usually focus on the debate on whether the Economic Conformance Level (ECL) model is valid. This debate is polarised by two approaches that are (1) the total quality cost approach and (2) the 'quality is free' approach (Maani, 1990; Reitsperger and Daniel, 1991; Marcellus and Dada, 1991; Bowman, 1994).

The ECL model assumes that increasing quality performance decreases quality failure costs and increases quality appraisal and prevention costs. Prevention and appraisal costs concern activities such as inspection, preventive maintenance, process control, quality training, laboratory and measurement. Failure costs concern internal losses such as materials scrap, rework and corrective actions and external losses such as warranty, liability, complaints and retrofits (Reitsperger and Daniel, 1991; Bowman, 1994). This CS trade-off becomes more important as the process reliability deteriorates. Thus, there is an economic conformance level where total quality costs are minimum (Figure 3-3). Since the appraisal and prevention costs are both positive, the ECL is below 100% quality.

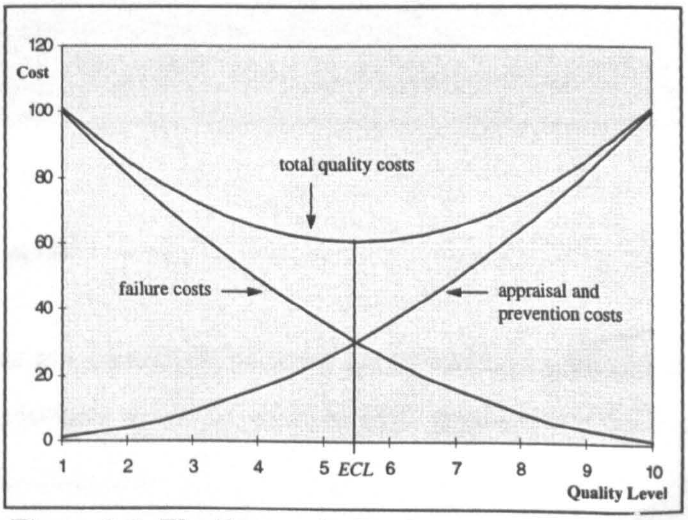

Figure 3-3: The Economic Conformance Level Model
Source: Reitsperger and Daniel, 1991

Some people argue that this view is inappropriate and has been misleading Occidental companies in making trade-offs while Japanese companies keep on looking for 'the last grain of rice' (Hayes, 1981). However, such a view was not corroborated by Reitsperger and Daniel (1991). Their empirical study on manager's quality perceptions in the USA and Japan suggested that USA managers were even more inclined to disagree with the ECL Model than their Japanese counterparts[7].

It seems that what really influences OM's perception on quality costs is the context of their companies. According to Maani (1990), in firms with good quality performance the prevention and appraisal costs correspond to about 65% of quality costs while failure costs correspond to 35%. This situation is inverse in firms with poor quality performance. There, failure costs may represent nearly 70% of quality costs. This not only means that firms with poor quality performance have more to benefit from increasing quality but also that, from their OM's point of view, quality improvements in the short-term are apparently 'free'.

On the other hand, it seems that usual sources of increasing cost efficiency decrease quality performance. According to Maani (1990), the negative impact of intensive-productivity strategies on quality is evident, specially in labour-intensive systems. Ferdows and De Meyer (1990) suggested that the impact of increasing cost efficiency on quality is at least neutral, if not negative.

- Below the Economic Conformance Level, production cost decreases as quality increases. Above this point, the literature points out a trade-off between quality and cost.
- Cost savings obtained through more intensive work decrease the quality performance.

3.3.6 Cost and Speed

The literature points out a trade-off between speed and cost productivity in mass production systems. Mass production is set to achieve high productivity through strategies such as

[7] The study asked 1570 Japanese and 1600 North-American managers whether they agreed with the proposition 'reducing rejects increases cost'. Among the Japanese, 18.7% agreed, 22.4% were undecided and 58.9% disagreed, while the correspondent proportions in the USA were 7.1%, 2.3% and 90.6%.

large batch sizes and high work-in-process levels. Large batches systems have low cycle times but high lead times, as batches have to wait a long time to be processed. The relationship between work-in-process levels and queuing time (one of the most important elements of lead time) is direct: increasing work-in-process increases - sometimes severely - queuing times (Crandall and Burwell, 1993).

Just-in-Time (JIT) systems challenged this trade-off. One of the key objectives of JIT is to reduce production lead times by minimising the cost and time spent in areas such as inventories, transport and set-ups. According to Monden (1990), this strategy may improve three major speed dimensions as follows:

- *Operations time* improves due to set-up time reductions, multi-skilled workforce and cellular layout (leading to smaller batches);
- *Transportation time* improves due to cellular layout and faster transport devices;
- *Waiting time* improved due to standardisation and group working (leading to balanced lines) and small batches.

Getting such benefits relies also on increasing flexibility types such as machine, labour and rerouting. Thus increasing operational flexibility types may improve the relationship between speed and cost (Kumar and Motwani, 1995).

- The literature points out a trade-off between cost and speed in mass production systems. Scale economies follow policies such as high batches and inventories, increasing lead times.
- Increasing flexibility types such as machine, labour and rerouting is one of the key strategies of JIT systems to improve the relationship between speed and cost.

3.3.7 Cost and Dependability

The relationship between dependability and cost is similar to that of quality and cost. Increasing dependability increases the cost with activities such as preventive maintenance and quality assurance and saves costs such as machine repairs, scrap and work-in-process

(Slack, 1991). According to Filippini, Forza and Vinelli's (1995) survey, increasing dependability is always associated with increasing production cost.

The total cost of dependability thus sums costs with providing dependability and costs with dependability failures. Since these are negatively correlated, there is a lowest point in the dependability curve corresponding to the 'Economic Dependability Level - EDL' (see Figure 3-4). The trade-off between dependability and cost productivity applies to any dependability improvements above such point.

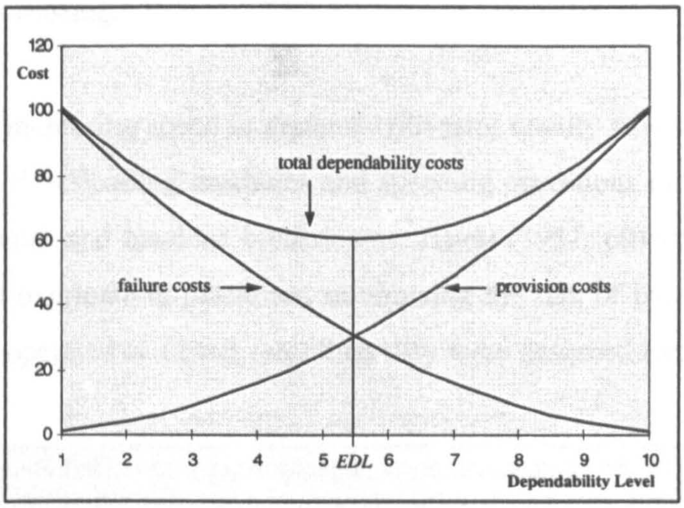

Figure 3-4: Dependability Costs
Source: Slack, 1991

The trade-off between cost and dependability was further investigated by Greis (1994). He suggested that its strength depends on external and internal factors such as the variability of demand, the cost structure and the capacity limits.

Increasing productivity due to more intensive work has usually a negative impact on dependability. Intensive work practices may cause disruptions due to quality problems and machine break-downs that undermine the dependability performance.

- The literature points out a trade-off between dependability and cost above the EDL.
- Increasing productivity due to intensive work practices may decrease the dependability performance.

3.3.8 Quality and Speed

According to Ferdows and De Meyer (1990), increasing quality increases speed but increasing speed decreases quality performance. They suggested that this trade-off works in one direction but not in the other.

According to Handfield and Pannesi (1995), high quality conformance minimises the occurrence of problems to speed such as material shortages, machine breakdowns and schedule instability. According to Cordero (1991), quality failures such as scrap and reworks mean time-wasting.

On the other hand, increasing speed in systems with poor quality may increase even further the quality failures. Overloading machines and speeding operations may lead to increasing levels of scrap, rework and machine breakdowns. Hayes (1981: 60) stressed that Japanese companies avoided overloading machines, minimising the risk of breakdowns and losses: "... machines often operated at slower rates than they were designed for..."

- The literature suggests that increasing quality performance increases speed.
- The literature suggests that increasing speed decreases quality performance.

3.3.9 Quality and Dependability

According to Ferdows and De Meyer (1990), quality conformance is positively related with on-time delivery. Major benefits from improving quality (such as lower scrap, rework and machine breakdowns) provide stability and predictability to sustain dependability. Likewise, increasing dependability increases the quality performance (Slack, 1991). Filippini, Forza and Vinelli (1995) suggested that such positive relationship characterises high-level customer service strategies.

These ideas suggest that there is no trade-off between dependability and quality. This is because quality and dependability rely on similar sources such as machine reliability, system's stability and predictability. Increasing quality develops capabilities that affect dependability in a positive manner.

- The literature suggests that increasing quality increases the dependability performance.
- The literature suggests that increasing dependability increases the quality performance.

3.3.10 Speed and Dependability

According to New (1992), there is a trade-off between speed and dependability. This trade-off affects specially make-to-order systems, although it may happen in make-to-stock systems as well. Shortening delivery times makes it harder meeting promises. Handfield and Pannesi (1992) provided the example of a firm whose sales personnel were promising each time larger delivery lead times to their clients so that schedules could be met. Similar situation seems to characterise the airlines' industry, where many companies have been able to reach higher dependability levels only by increasing the duration of their flights.

New (1992) suggested that one may improve this trade-off through strategies of high process repeatability and low buffers. The problem is that fewer companies compete still in bases of high repeatability. Handfield and Pannesi (1992) suggested improving speed and dependability by strategies that are not directly related. Improving speed may rely on strategies such as low buffer and batch sizes. Dependability may rely on better scheduling.

Slack (1991) proposed that speed and dependability may be mutually supportive. Fast lead-times make it easier meeting delivery promises. Increasing dependability increases the system's reliability, minimising disruptions and delays. However, as Filippini, Forza and Vinelli (1995) pointed out, such mutual benefits requires the development of successful time-based strategies.

The trade-off between speed and dependability thus depends on the distinction upon production lead times and delivery promises. The problem highlighted by Handfield and Panessi (1992) is due to a practice of promising delivery times that are too close to the production lead times. In this way, any disruption may cause delivery delays. To reduce such problems, OM has to keep delivery promises well above production lead-times (see Figure 3-5). Naturally, this depends on the customers expectations and competitors' practice. Fierce competition may require tightening promised delivery times.

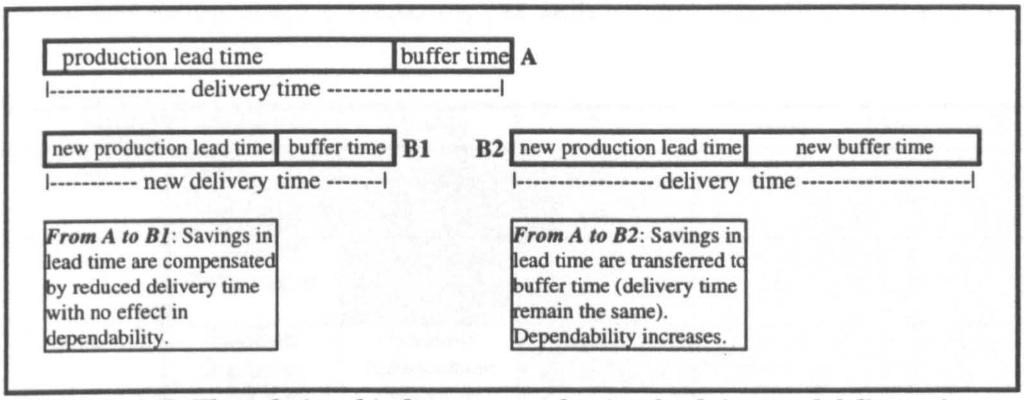

Figure 3-5: The relationship between production lead time and delivery time

That means the trade-off between speed and dependability is actually a trade-off between delivery promises and dependability. Increasing speed only increases dependability if delivery promises are not shortened in the proportional extent.

- The literature points out a trade-off between speed and dependability. This strengthens as delivery promises equal production lead times.
- Increasing dependability increases the speed performance.

3.3.11 Section Conclusions

Section 3.3 reviewed the relationships between the five MSDs defined in Chapter 1. This literature suggested the existence of four major types of relationships (see Table 3-3):

- Trade-off (9 occurrences) This is a compromise between the variables. Improving one variable can only be obtained at the other's expense;
- Enhancement (5 occurrences): There is no compromise between the variables. Improving one variable may improve the other's performance;
- Improving (4 occurrences): Improving some factors may improve an existing trade-off between the variables;

- Contingent (6 occurrences): The relationship between the variables may be either a trade-off or enhancement. This depends on factors such as (1) the performance of the variables; (2) the direction of the improvement, that is which variable is improved first; (3) competitive factors that may affect the importance of the variables and (4) infrastructure factors such as technology or abilities that may affect their performance.

versus	Flexibility	Quality	Cost	Speed	Dependability
Flexibility					
Quality	Trade-off Enhancement				
Cost	Trade-off Improving Contingent	Trade-off Enhancement Contingent			
Speed	Trade-off Improving Contingent	Trade-off Contingent	Trade-off Improving		
Dependability	Trade-off Enhancement	Enhancement	Trade-off Enhancement Contingent	Trade-off Improving Contingent	

Table 3-3: Types of relationships between manufacturing dimensions

Table 3-3 does not exclude the occurrence of any type of relationship between MSDs. It only summarises the major propositions from the literature. It shows that different studies may disagree on the types of relationship that may characterise pairs of MSDs. Two hypotheses may explain such disagreement: (1) these relationships have not been properly investigated or there is a need for further theoretical and empirical studies in this area; (2) all propositions are true, following the dynamic approach of trade-offs for which (a) these relationships are contingent (depend on circumstances) and (b) they are dynamic, as one may improve trade-offs.

3.4 Chapter Conclusions

Chapter 3 reviews the literature on manufacturing trade-offs. Sections 3.1 and 3.2 discussed theoretical aspects of trade-offs and their role in operations systems. Section 3.3 discussed the relationships between different MSDs. The propositions at the end of each sub-section refer to the type of relationships that may characterise each pair of MSDs in the literature. The research model and propositions will ground in great extent on such propositions.

The understanding of trade-offs is of major relevance for MS. Trade-offs affect major MS aspects such as its process, the setting of strategic priorities and the approach of decision-making. Thus improving the knowledge about trade-offs may improve the development and the effectiveness of MS.

The prospects for a dynamic view of trade-offs seem good. This view seems to be the one that best explains phenomena such as the impact of new technologies, the role of capabilities, the setting of competitive priorities and the (proactive) role of manufacturing. However, this theory is still recent and requires extensive development.

Section 3.3 thus reviewed the nature of the relationships between MSDs. Different types of relationships characterise different pairs of dimensions. Above all, these relationships seem to be dynamic and contingent, as stressed in studies[8] reviewed in Section 3.2.

This review suggests some questions that may be open for further investigation in this and in subsequent studies:

1. Slack's (1991) pivot and Hayes and Pisano's (1995) improvement trajectories support the idea of dynamic trade-offs and of OM's ability to change trade-offs. However, one should test what constitutes these concepts in practice: organisational capabilities (as in Hayes and Pisano, 1995), technical and attitudinal constraints (as in Slack et al., 1995), manufacturing flexibility, resources or another idea;
2. One has to clarify the nature of trade-offs in the context of operations. The literature seems to be growing towards a dynamic and contingent view of trade-offs that is opposed to former MS ideas and the WCM theory alike. However, this literature is mostly theoretical and lacks a solid empirical support for such propositions. Thus an in-depth and explanatory study of trade-offs in the context of organisations seems to be necessary at this stage to clarify such aspects;
3. This leads to a more general drawback of this literature, concerning its excessively 'descriptive' approach (Do trade-offs exist? What does constitute trade-offs?). 'Why'

[8] Filippini, Forza and Vinelli (1995) survey found a high incidence of both trade-offs and compatibility for different pairs of MSDs. This reinforces the contingent view of trade-offs and undermines the generalisability of the relationships discussed along section 3.3.

and 'how' questions seem more necessary at this stage than 'what' questions. There is little knowledge about, for instance, how one deals with trade-offs, how they affect the MS formulation and improvement, why trade-offs exist, etc.;

4. Finally, there seems to be a major confusion regarding the ideas of flexibility and variety and their role in trade-offs. Some studies investigate trade-offs involving flexibility, while others investigate trade-offs involving variety. Furthermore, variety is one of the dimensions of flexibility; flexibility has been considered a MSD like cost and speed (which are also dimensions of flexibility); trade-offs between flexibility and cost involve variety, albeit they are different from trade-offs between *variety* and cost, etc. These paradoxical ideas (not all correct, most ill-defined) reflect that confusion discussed above. Since these problems often involve trade-offs, their investigation has to make part of this study.

Part II - Research Methodology

Part II discusses the methodological aspects of this research. It combines the literature reviewed in Part I with sources on research methodology to define the framework, methods and design of the investigation. Part II is divided into three chapters:

Chapter 4
Research Framework

Chapter 5
Research Methods

Chapter 6
Research Design

Chapter 4 - Research Framework

Chapter 4

Research Framework

Introduction

Chapter 4 discusses the objectives and framework of this study. The framework consists in a research model and a series of propositions to guide the investigation. Section 4.1 presents the research model. Section 4.2 discusses the primary and secondary objectives of the study. Section 4.3 discusses the working propositions to be used along the investigation. These propositions will be later compared with the research data and the literature to help generating the study's results and conclusions.

4.1 The Research Model

This section discusses the research model to be used along the data collection and analysis. Each element involves a definition and function within the framework.

4.1.1 Manufacturing Trade-offs

Manufacturing trade-offs are compromises between different MSDs or decisions (Skinner, 1969). The existence of trade-offs implies that production systems can not achieve everything and that their performance depends on a number of factors. This research is about trade-offs between the five MSDs defined in Chapter 1: cost, quality, flexibility, dependability and speed.

In its deterministic approach, managing a trade-off between variables 'A' and 'B' means deciding whether to (1) maximise the performance of 'A + B', (2) maximise the performance of only 'A' or (3) maximise the performance of only 'B'. The existence of this trade-off means there is no such option as 'maximise A + maximise B' as if they were independent. Figure 4-1 illustrates these options:

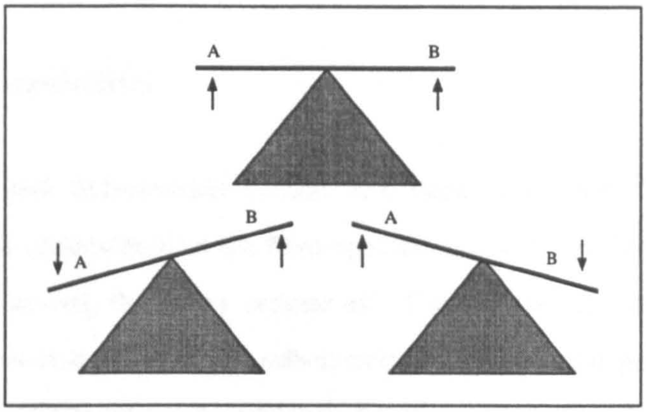

Figure 4-1: The management of manufacturing trade-offs

4.1.2 Dynamic Trade-offs: Moving the Pivot

As discussed in chapter 3, the deterministic view of trade-offs no longer characterises the MS literature. Skinner (1992) suggested a new approach for which trade-offs are as real as ever but alive and dynamic. Trade-offs may be changed, improved if necessary. As manufacturing firms operate within different strategies and environments, this approach suggests that the importance and strength of trade-offs depend on such circumstances. This approach corresponds to work propositions ***WP1*** and ***WP2***.

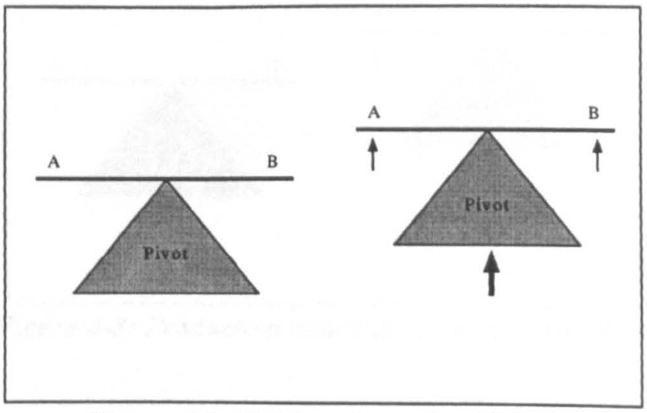

Figure 4-2: Raising the trade-off pivot

This approach brings a new element to the context of trade-offs, called the pivot. The pivot represents the internal and external factors that influence the importance and strength of trade-offs (the combined performance of its variables)[1]. To raise the pivot of a trade-offs is to improve the performance of its two variables at once. Figure 4-2 illustrates this idea.

4.1.3 Production Capabilities

According to Amit and Schoemaker (1993: 35), capabilities are "... information-based, tangible or intangible processes that are firm-specific and are developed over time through complex interaction among the firms' resources". Capabilities are the range of functions, activities of processes that a machine, sub-system or system can perform (Tincknell and Radcliffe, 1996). Examples of production capabilities are product development, customer services, process control and machine set-ups.

Production capabilities link the firm's resources with its objectives. Increasing a firm's performance requires increasing its capabilities and resources. If production capabilities are the major determinants of performance, it is reasonable to propose that they are the trade-off's pivots (this is work proposition ***WP3***). This means that production capabilities bound the performance of trade-offs and thus increasing a trade-off's pivot is increasing its related capabilities (Figure 4-3).

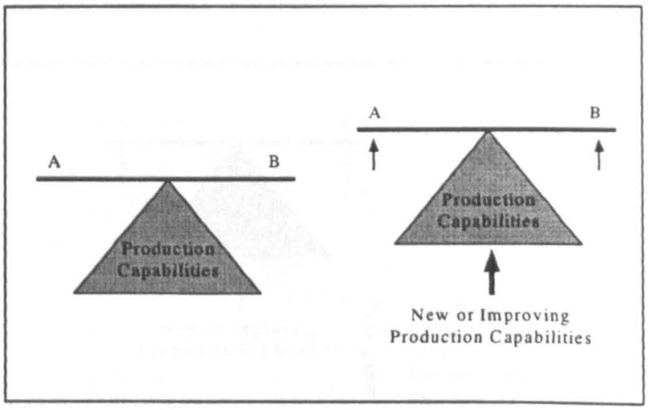

Figure 4-3: Production capabilities as trade-off pivots

[1] Some of the ideas discussed in this Chapter have obviously changed or been improved after the data collection and analysis process. Chapters 8, 9 and 10 discuss such changes in various opportunities. It should be considered that this chapter was written before the data collection and analysis. Its only sources are the literature and the researcher's views on the matter.

4.1.4 Flexibility Capabilities

As production capabilities represent the processes or activities performed in a production system, the number of different capabilities that may be identified within a system can be very large. Each capability relates to specific MSDs. The capabilities relating to a specific dimension are the ones that directly sustain the performance of that dimension.

Chapter 2 reviewed the production capabilities relating to flexibility. Each flexibility capability relates to specific flexibility types and levels. Since capabilities mean activities, and activities are composed by infinite levels of aggregation, the identification of different types of capabilities in each system's level is natural and expected. Flexibility capabilities are thus activities or processes, at various levels, that support the flexibility performance.

The importance attributed in this study to flexibility capabilities in the context of trade-offs follows the importance of flexibility for many production strategies and objectives (Chen, Calantone and Chung, 1992; Slack, 1991). According to Slack (1991), increasing flexibility has a positive impact on objectives relating to speed and dependability. Chen, Calantone and Chung (1992) stressed its importance for strategies such as increasing buyer concentration and innovativeness. Flexibility capabilities are major assets whose importance goes beyond the flexibility dimension.

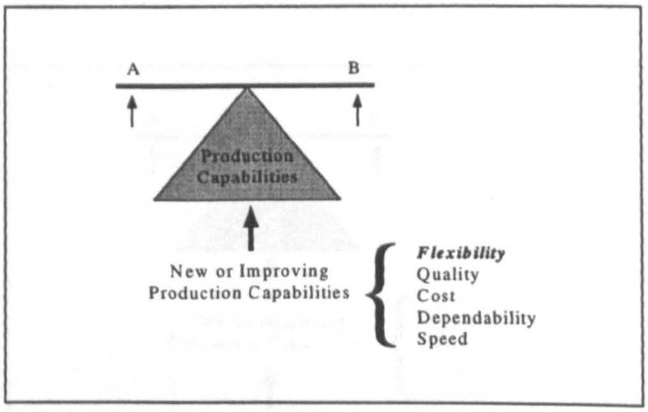

Figure 4-4: Flexibility capabilities as the major research focus

Thus, as this study aims to investigate the impact of production capabilities on trade-offs, and given the practical benefits of focusing on a specific dimension, the most appropriate seems to be flexibility. Besides the importance of flexibility discussed above, the literature reviewed in Chapter 2 offers a great deal of flexibility propositions, variables and measures that meet this research framework's needs. This study's focus on flexibility is further endorsed in work proposition ***WP5***.

4.1.5 Manufacturing Resources

The new paradigm in manufacturing and business strategy views resources as the major sources of development of capabilities (Hayes and Pisano, 1994; Grant, 1991; Wernerfelt, 1984). According to Wernerfelt (1984), examples of resources are facilities, experience, people and customer loyalty. By developing its resources, the firm increases the potential of its capabilities and competitiveness.

Manufacturing resources best relating to the development of production capabilities are technologies (equipment and software) and work methodologies such as work policies and systems (Roth and Miller, 1992). The literature provides a broad range of technologies and methodologies relating to the development of flexibility, presented in Chapter 2.

Manufacturing resources are the last element of this research model. This study focuses on the flexibility technologies and methodologies reviewed in Chapter 2 as the major resource types to influence trade-offs[2]. The role of manufacturing resources in trade-offs is further explained in the work proposition ***WP4***.

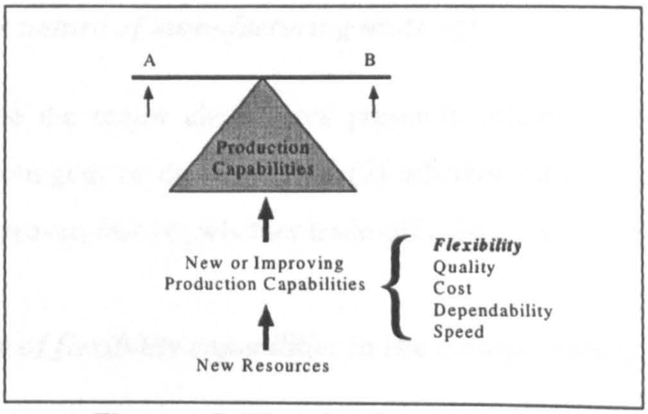

Figure 4-5: The role of new resources

[2] As suggested in chapter 2, the impact of flexibility technologies and methodologies goes well beyond the flexibility dimension. In fact, this range comprises the majority of technology and methodology types usually considered in OM studies.

4.2 Research Objectives

This section discusses the primary and secondary objectives of this research. The secondary objectives correspond to subjects that should be investigated to help the successful achievement of the primary objective. These objectives are related, as demonstrated in the research model and propositions.

Primary Research Objective

This research aims to extend the knowledge on the sources, nature, effects and management of manufacturing trade-offs. This is about the ways that OM may assess and deal with trade-offs to be able to combine different objectives in the same manufacturing strategy.

Secondary Research Objectives

1. To investigate the relationship between trade-offs and production capabilities.

This is about aspects of the correlation between production capabilities and trade-offs within manufacturing systems, such as (1) whether and how capabilities influence trade-offs; (2) whether capabilities act as trade-offs pivots and (3) whether and how trade-offs benefit from the improvement of capabilities.

2. To investigate the nature of manufacturing trade-offs.

That is to investigate the major alternatives presently relating to trade-offs such as (1) whether they are contingent or deterministic; (2) whether they are static or dynamic; (3) how they may be improved and (4) whether trade-offs always exist or may be eliminated.

3. To define the role of flexibility capabilities in the manufacturing trade-offs context.

This concerns aspects such as (1) if there is a relationship between capabilities and trade-offs, what is the role of flexibility capabilities in this relationship; (2) how successful are flexibility capabilities in improving trade-offs and (3) which flexibility capabilities can be linked to the improvement of specific trade-offs.

4. To define the role of flexibility resources in the context of production capabilities.

This involves investigating questions such as (1) how one should manage the implementation of technologies and methodologies to effectively improve capabilities and trade-offs and (2) which flexibility technologies and methodologies can be related to the improvement of specific capabilities or trade-offs.

4.3 Research Propositions

The research objectives and model may lead to work propositions to guide the process of data collection and analysis. Depending on the results of the data analysis, these propositions will (a) ground this study's results and conclusions or (b) lead to new propositions that are more appropriate to describe the reality as interpreted in the case studies. This study grounds on five work propositions based on the literature and research model and objectives as follows:

WP1 Manufacturing trade-offs are contingent. (New, 1992; Slack, 1991)

The strength and importance of a trade-off depend on environmental characteristics such as the system's resources, strategy and competitive needs. Since these factors are contingent, the performance and importance of specific trade-offs vary across different systems.

WP2 Manufacturing trade-offs are dynamic. (Skinner, 1992; Slack, 1991; Hayes and Pisano, 1994)

If trade-offs are contingent, it is possible to challenge and overcome specific trade-offs by improving the environmental characteristics upon which they rely (Slack, 1991). This is to increase the trade-off 'pivot' so that both trade-off variables may improve simultaneously. New technologies and methodologies have been increasingly successful because of their ability in improving capabilities to benefit many areas (instead of improving specific manufacturing objectives at other's expense). Instead of focusing on objectives, managers should select the trade-offs to improve (Hayes and Pisano, 1994).

WP3 Production capabilities act as trade-off's pivots. (Stalk, Evans and Shulman, 1992; Filippini, Forza and Vinelli, 1995)

Developing production capabilities is the most effective way of improving the performance of opposing MSDs (Stalk, Evans and Shulman, 1992). Filippini, Forza and Vinelli (1995) found a good correlation between distinctive competencies and the compatibility of MSDs. Distinctive competencies are the most important and strong capabilities. Thus, it seems that developing the system's capabilities means increasing its trade-offs pivots.

WP4 The major benefit of new technologies and methodologies is that of improving production capabilities that will improve trade-offs. (Skinner, 1992; Roth and Miller, 1992; Hayes and Pisano, 1994)

New technologies and methodologies change the relationship between different MSDs and thus the factors that influence trade-offs (Skinner, 1992). The implementation of new technologies and methodologies must focus on the development of useful capabilities instead of isolated performance objectives (Hayes and Pisano, 1994). According to Roth and Miller (1992) the three major building blocks of production capabilities are resource improvements, quality management programs and advanced process technology. These represent those new technologies and methodologies.

WP5 Flexibility capabilities are the most influential to manufacturing strategies. (Hayes and Pisano, 1994; Chen, Calantone and Chung, 1992; Schroeder et al., 1995)

Flexibility is the major competitive feature in the 90's (Ferdows and De Meyer, 1990; Bolwijn and Kumpe, 1990; Hayes and Pisano, 1994). The development of flexibility capabilities concerns not only flexibility strategies but also major strategies such as short product life cycles, increasing buyer concentration and innovativeness (Chen, Calantone and Chung, 1992). Because of the importance of flexibility as a feature of most new technologies, these technologies are often called 'flexible technologies', in spite of affecting the whole MSDs. Flexibility is probably the dimension with greatest 'internal' importance, since its ability to support strategies in other dimensions.

Chapter 5 - Research Methods

Chapter 5

Research Methods

Introduction

This chapter discusses aspects of research methods to be considered in study. It concerns six major subjects that are (1) OM research, (2) quantitative versus qualitative approaches, (3) research design, (4) field work, (5) data collection and (6) data analysis. This chapter aims to discuss the alternative methods used in social sciences and define the alternatives to ground this study. These definitions follow the objectives and framework discussed in Chapter 4. They are summarised in the chapter conclusions.

5.1 Operations Management Research

Operations management is a very dynamic research field, specially because it involves changeable aspects such as technology and competitive practices. OM research has to be constantly updated to provide solutions that effectively help managers in practice.

Achieving this objective requires OM researchers to use research methods that may improve the effectiveness and efficiency of their work. This is a major concern in the present days. Specially from the 80's, the literature on OM research methods has been increasing considerably (e.g. Andrew and Johnson, 1982; Chase and Prentis, 1987; Saladin, 1984; Miller and Grahan, 1981).

Following this development, this section discusses aspects of OM research that should be considered in this study. It focuses on three major aspects that are the research cycle, shortcomings of OM research and strategies of management research.

5.1.1 The Research Cycle

The research cycle is the combination of apparently different conceptual methods into an evolutionary process of theory development. Meredith et al. (1989) proposed that the OM research cycle consists in three stages of theory development. These are descriptive research, explanation and testing.

Descriptive research aims to report facts and events so that they may be acknowledged. One builds models to represent and help the interpretation of reality. *Explanatory research* aims to build concepts and explain the relationships between facts and events. It usually grounds on frameworks and hypotheses to explain these relationships. *Testing* aims to evaluate the concepts proposed by explanatory research through accepting or rejecting their propositions. Testing leads to a better identification and description of research phenomena and restarts the research cycle.

Each research stage relates better to specific conceptual methods. Meredith (1993) defined seven types of conceptual research methods. Three are conceptual models, that are 'simplified representations or abstractions of reality'. Three others are conceptual frameworks, that are more developed concepts of 'epistemic propositions or explanatory elements'. The last type are theories. These follow Dubin's (1969) five requirements in that true theories should: (1) allow prediction or increased understanding; (2) be interesting; (3) include attributes or variables and their interactions; (4) do not include composite variables and (5) include boundary criteria. The seven methods are the following:

Conceptual Models

1. **Conceptual Description** - Describes a phenomenon, without explaining why it happens, but only how it is characterised;
2. **Taxonomies and Typologies** - List items along one dimension (taxonomies) or more (typologies). As above, they characterise facts but not their relationships;
3. **Philosophical Conceptualisation** - Integrates different studies on a subject by summarising, comparing and contrasting their ideas. The MS concept is an example of philosophical conceptualisation, as it merges 'independent' concepts in one construct.

Conceptual Frameworks

1. **Conceptual Induction** - Explains phenomena by observing the relationships between their elements. This is to answer what the phenomenon is and how it occurs;
2. **Conceptual Deduction** - A framework is postulated and its predictions are detailed and compared with the reality;
3. **Conceptual Systems** - Considers not only the elements of a framework but also their interactions. It is almost a theory but fails to satisfy one or more theory's requirements.

Theories

1. **Meta-frameworks** - This is the only example of theories in this taxonomy. It is the compilation and integration of previous frameworks to build and delimitate a theory.

This research is ***explanatory*** and aims to build a ***conceptual system*** to improve the knowledge of manufacturing trade-offs. This framework should identify and explain the different elements of trade-offs as well as their relationships. The construction of a theory would demand the compilation of previous frameworks on trade-offs that can not be provided by the current literature.

5.1.2 Shortcomings in Operations Management Research

Meredith et al. (1989) pointed out some shortcomings in the current OM literature:

Narrow instead of broad scope: OM studies focus often on problems of limited influence or magnitude. These are easier to investigate than problems relating to many levels and functions of a system. However, the investigation of problems of broad scope is the one that changes paradigms and creates new theories. In theory development, few large steps are usually more important than many small steps.

Technique instead of knowledge orientation: According to Voss (1984), OM studies consist often in the application of operations research methods in practice. This approach is appropriate for 'classical' problems but not for those not well understood. The application of techniques is also difficult in problems in which variables and relationships can not be entirely described. These require the application of knowledge-oriented research to explore, describe and formulate hypotheses to understand and formulate a theory for the problem. This criticism may no longer be valid given the last developments in OM research, but it remains a useful advice.

Abstract instead of reality perspective: Meredith (1993) surveyed papers published in 11 OM journals between 1982 and 1987. Among the 362 papers analysed, only 16% were based on true empirical methods (survey, case study, field study). The remaining 84% consisted in modelling, simulation, conceptual and laboratory experimentation studies. Current OM studies usually consist in laboratory methods. There is a lack of use of empirical methods such as field studies. This may lead to problems such as the under-estimation of reality and the formulation of theories that do not consider many relevant variables of a phenomenon. The gap between OM theory and practice was emphasised by Flynn et al. (1990). They said that it characterises specially research projects lacking the financial or time resources required for field studies.

There is a concern to avoid these shortcomings in this research. This study aims to **understand** the relationship between trade-offs, capabilities and flexibility within a **broad scope** of production systems, using a **reality perspective** based on empirical research.

5.1.3 Strategies of Management Research

The research strategy represents how the researcher intends to build or test theory in the study. The choice of a research strategy depends on aspects such as the state of development of a subject, the type of questions being made and the range of 'independent' theories to support the elucidation of these questions. Reisman (1988) and Reisman and Kirschnick (1995) defined seven research strategies used in management studies as follows:

1. **Ripple Strategy** - Incremental strategy. One refines a model for *n* dimensions to include *n+1* dimensions;
2. **Embedding Strategy** - Several models or theories are embedded in a more generalised or global theory;

3. **Bridging Strategy** - Bridging known models or theories to develop a new theory that is bigger than the sum of its parts;
4. **Transfer of Technologies Strategy** - Using what is known in one discipline to model, by analogy, a problem whose domains fall in another discipline;
5. **Creative Application Strategy** - A direct transfer of technologies, with no need for analogy;
6. **Structuring Strategy** - Appropriate for a universe of problems quite unexplored by contemporary science. This requires much exploratory research and the development of grounded theory;
7. **Empirical Validation Strategy** - The verification of empirical validity or applicability of known theories.

According to Reisman (1988), the ripple strategy is the best accepted in science journals presently. However, there should be a continuous effort to do more embedding and bridging research to avoid we being 'buried' in our models. These are the strategies that lead to new models and expand the limits of our knowledge.

This research relates to the ***bridging*** strategy. The linking of theories of production capabilities, manufacturing flexibility and trade-offs should lead to a better understanding of their role and relationships in manufacturing systems.

5.1.4 Section Conclusions

Section 5.1 discussed some methodology aspects of major relevance in today's OM research. It aimed to define the objectives on the methodology of this study that may reflect the concerns unveiled in this review.

Three types of objectives may be suggested here. The first concerns the research proposition, the second concerns its strategy and the third relates to the type of results it should generate. The methodology objectives of this study are thus as following:

Proposition

- **Empiricist**: The research will focus on the reality perspective and base its conclusions on empirical evidence;

- **Broad scope**: The research aims to study the relationship between trade-offs, capabilities and flexibility in a broad scope of production systems;
- **Knowledge orientation**: This research aims to build conclusions through knowledge application rather than operational techniques.

Strategy

- **The bridging strategy**: This study aims to build a theory concerning the relationships among trade-offs, capabilities and flexibility starting from propositions in their own theories;
- **Explanatory**: It aims to explore the concepts of trade-offs, capabilities and flexibility and their relationships in manufacturing systems.

Results

- This study will **build theory** (structural corroboration) rather than test theory;
- This theory building concerns the construct of a **framework** of the relationship between trade-offs, capabilities and flexibility.

5.2 Quantitative versus Qualitative Research Approaches

The choice of a research approach is one of the major decisions in research methods. Each research approach has different implications to aspects such as the research objectives, the data collection methods and the type of conclusions that one may generate. There must be a high consistency between these aspects and the selected research approach. The basic research approaches are the qualitative and quantitative.

This section describes and compares these approaches to define the one that is more appropriate for this study.

5.2.1 The Qualitative Research Approach

The use of qualitative approaches in management studies has been increasing since the late 70's (Morgan and Smircich, 1980). It follows concerns that management studies should be more context-dependent, permitting a greater contact between theory and data, context and investigator. The nature of organisations requires explanatory studies to investigate inside their structures if one wants to build new theory instead of testing hypotheses (Van Maanem, 1979; Kaplan, 1988).

The qualitative approach is a feature of many 'interpretative techniques' which, according to Van Maanem (1979: 520), "... seek to describe, decode, translate and otherwise come to terms with the meaning, not the frequency, of certain more or less naturally occurring phenomena in the social world". This is an investigative, explanatory approach, aiming more to explain than to describe facts and events.

According to Yin (1984) qualitative methods are characterised by (1) detailed observation and involvement of the researcher and (2) the avoidance or prior commitment to theoretical propositions. Scientists are expected to investigate within the subject to describe it and construct a model to explain it. Collected data are mainly interpretative, serving both to refine and to resolve the research questions. Hypotheses are defined and changed according to the data collected and their comparison with previous literature. The only truly 'prior' element in its design is the set of research questions to drive the study (Kaplan, 1988; Morgan and Smircich, 1980).

The most common qualitative data collection methods are observation and interviewing. These methods seem to be more compatible with the depth, flexibility and exploratory abilities demanded by theory building studies, specially in social sciences.

5.2.2 The Quantitative Research Approach

Quantitative methods refer to the 'traditional' approach of natural sciences that is theory modelling, hypotheses generation and hypotheses testing. One tests hypotheses through experiments or statistical data analysis where theory concepts turn into models' variables. Hypotheses are accepted or rejected depending on the value of these variables after the data collection and analysis. If hypotheses are accepted, the research questions are considered successfully answered. Otherwise, the researcher has to define new hypotheses or to revise his initial assumptions.

These procedures follow the positivist definition of science for which only large empirical testing proportionate factual discovery (Kaplan, 1988). The world is seen as a concrete set of elements subjected to deterministic forces. The investigator has to abstract these elements from their context to explain their characteristics and relationships (Morgan and Smircich, 1980).

The major concern in quantitative research is complying with validity parameters. These parameters indicate whether one may accept the results of a research. According to Correa (1992), these parameters are (1) causality, that is the findings need to explain how things became as they are; (2) generalisation, that is findings must be applicable beyond the limits of the study and (3) replication, allowing other studies to employ its original procedure to test its validity.

In spite of their common use in the natural sciences, exclusive use of quantitative methods in social sciences has been criticised. They are said to have problems such as (Kaplan, 1988; Van Maanem, 1979):

1. The excessive ritualization of procedures, losing the connection between measure and concept;
2. The nature of social systems and their many unidentified and uncontrolled variables may turn it very difficult isolating facts from their context and finding explanations based only on objective measures;
3. The simplification and abstraction that remove features from the subject of study;
4. Most importantly, the view that science development cannot progress only by the incremental gains of such methods, which are accurate but slow and expensive.

5.2.3 The Choice of a Research Approach

Qualitative and quantitative approaches as described above are polar approaches. Research studies usually combine both approaches rather than 'choose one'. Nevertheless, it is important defining which research approach will distinguish the study and guide the choice of its design variables. This definition depends on the comparison between the approaches characteristics and the study's objectives, strategy and subject (Morgan and Smircich, 1980). Table 5-1 describes these characteristics.

Choice Criteria / Research Approach	Qualitative	Quantitative
1. Sciences branch best associated with	social sciences	natural sciences
2. Appropriateness to organisational studies	high	low
3. Research aim best associated	theory building	theory testing
4. Major research question type	the meaning of facts	the frequency of facts
5. Relationship between investigator and subject	involvement	distant
6. Commitment to theoretical prepositions	not existent	existent
7. Analysis of facts	in context	out of context
8. Allow changes in research direction	yes	no
9. Manner of data judgement	objective/subjective	objective
10. Replicability	low	high
11. Generalisability	low	high

Table 5-1: Characteristics of Research Approaches

Given these characteristics and this study's objectives, strategy and subjects, the qualitative approach seems to be the most appropriate for the research design. This approach combines better with major aspects of this study (in Section 5.1.4) as follows:

1. This research relates to business *organisations*, in the context of *social sciences*. That fits with the 1st and 2nd qualitative criteria;
2. The major research aim is to *build theory* on the relationships between trade-offs, capabilities and flexibility. That fits the 3rd criterion;
3. The major research questions concern *whether* trade-offs exist, *what* is their importance and performance, *how* they may be improved and *what* is the role of flexibility and capabilities in this context. That fits the 4th criterion;
4. Given this study aims, the research expects (a) a major *involvement* with the field cases and (b) the analysis of facts *in their context*. That fits the 5th and 7th criteria;
5. The *low commitment* to prior theory or concerns and the *objective/subjective analysis of data* fit the 6th and 9th criteria.
6. The *flexibility* of a qualitative approach meant by the 8th criteria fits the broad scope of investigation.

This research major approach may be thus called ***qualitative***. This does not bar, however, the use of quantitative methods or quantitative measurement of data if necessary. Above all, the research design must be flexible to permit the achievement of the objectives of the study. These do not relate to its methods but to its subject.

5.3 Research Design

The research design is the action process that "... guides the investigator in the process of collecting, analysing and interpreting observations." (Nachmias and Nachmias, 1976: 77). It concerns the strategy of investigation for the study. The research design is the process connecting the empirical data to the questions and leading to the conclusions (Yin, 1984).

The choice of a research design paradigm is the third step in the methods definition. This section describes and compares the main paradigms currently used in OM research. The paradigms are compared along parameters defined in the literature. This comparison leads to the identification of the most appropriate paradigm for this study.

5.3.1 Research Design Paradigms

Experiments: Research experiments aim to describe phenomena by controlling and even determining the value of independent variables that affect it. Facts are investigated out of their context: reality is represented as a model of cause and effect. Experiments assume that, by controlling the events causes, their effects may be well determined and their relationships successfully established. (Meredith et al., 1989)

This is the most common research paradigm in natural sciences. Experiments have been also extensively used in social sciences but with results not always satisfactory. Social sciences subjects concern usually many different variables, making it difficult to construct laboratory models. The Hawtorne experiments - probably the most famous case of using experiments in social research - are a major example of this difficulty.

Surveys: Surveys investigate events through the interpretation of the accounts of people in their context. They usually gather a large number of respondents to allow the use of statistical methods in data analysis and hypothesis testing. They have the ability to focus on the factors of major interest for the researcher (Meredith et al., 1989).

There are two basic approaches in survey's design. First, they may focus on a sample of elements with a predetermined common characteristic. Alternatively, they may investigate a large, randomly chosen sample. The first strategy is more appropriate for investigating phenomena characterising a small share of the population. The second is more appropriate for generalised phenomena (Flynn et al., 1990). The major challenge in surveying companies seems to be the increasing 'complaint' about the growing number of surveys they have been asked to respond. This leads to lowering standards in both the number and the validity of returned questionnaires in typical studies.

Historical Analysis: Historical analysis has been considered either a research design paradigm (Meredith et al., 1989; Yin, 1984) or a data collection method used in conjunction with other paradigms, often case studies (Flynn et al., 1990). Historical analysis investigates phenomena by examining, comparing and interpreting historical documents and data of similar nature. Its major difference from other paradigms is that its data come from past records not built by the researcher. The only 'active' role of the researcher is on selecting the documents that may be relevant.

This method is not as frequently used in OM studies as surveys or case studies. However, this may be sometimes the only appropriate strategy, specially in studies on past events.

Field Studies/Field Experiments: These methods apply the principles of classical experiments into natural settings instead of laboratories. The researcher selects a group of sites that are consistent with pre-defined characteristics, permitting the evaluation of parameters at different levels. The major difference between field studies and field experiments is that field studies control only the selection of sites, while field experiments may specify the value of field variables (Meredith et al., 1989).

Field studies and experiments are particularly interesting for management studies on hypotheses testing. Their external validity is greater than that of laboratory experiments as they take place in natural settings (Flynn et al., 1990). However, their use alongside theory building studies has some problems, the major being the limit for the number of variables that they may successfully cope with.

Action Research: This is considered the most interactive method used in OM research. Action research aims not only to investigate a system but also to intervene and improve its operations (Manion, 1994). The researcher not only investigates a group but makes part of it. The major advantage of this method is thus the offering of an immediate benefit to the organisation in study (Meredith et al., 1989). This may improve the relationship between researcher and organisation.

Because of the 'improvement' orientation of action research, the practice ability and the experience of the researcher have great importance (Platts, 1993). This method requires usually much more field time than the others. The researcher has usually to participate in all the stages of a typical project even if he is interested only in a particular stage.

Action research has some advantages over the non-intervening, 'positivist' methods. It is oriented to immediate improvements, it is collaborative, it is situational[1]. Nevertheless, the achievement of such benefits requires experience and a long and intense collaboration between investigator and organisation. It also requires the overcoming of some ethical and methodological dilemmas in social sciences (Rapoport, 1970) that still limit its appropriateness in many cases.

Case Studies: Case studies investigate phenomena in-depth and in their original context (Meredith et al., 1989). They are interpretative, observational and oriented to in-depth studies. Case studies may involve single or multiple sites. Each site may include different levels of analysis, data collection methods and analysis procedures (Eisenhardt, 1989). Because of their flexibility, case studies have been commonly used in OM research, specially in exploratory and theory building studies.

According to Meredith et al.(1989), case studies are specially appropriate to explanatory studies involving 'how' and 'why' questions. According to Eisenhardt (1989), they do not rely on previous literature or empirical evidence, but on the investigation of current events

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[1] A major discussion of such aspects may be found in Susman and Evered (1978) and Rapoport (1970).

in their context. Thus they are specially useful in theory-building studies on subjects with little 'empirical substantiation' or exposed to intense debate.

Case studies may involve single or multiple sites. Multiple case studies do not necessarily require the duplication of data collection procedures along sites (Flynn et al., 1990). The form and content of data may vary according to the characteristics and needs of each site.

5.3.2 Comparing Research Design Paradigms

The choice of a research paradigm depends on the characteristics, objectives and strategy of the study. The most appropriate paradigm is the one that best matches these characteristics.

The literature provides different frameworks for the comparison of design paradigms. Yin (1984) proposed that the choice of a paradigm should follow three questions:

1. **What is the type of research question posed?** The basic types of research questions are 'who', 'what', 'where', 'how' and 'why'. The 'who' and 'where' questions are descriptive or prescriptive, while 'how' and 'why' are essentially explanatory (see section 1.5). 'What' relates to both purposes;
2. **Does the investigator have control over behavioural events?** Sometimes the investigator may state *a priori* the level of variables relating to the phenomena. Other times, these are beyond his control;
3. **Does the research focus on contemporary or historical events?** Some research studies are essentially historical, while other concern present events.

Meredith et al. (1989) proposed a framework, based on Mitroff and Mason (1984), that has two dimensions and is considered adequate to the OM context. The first dimension is the rational/existential "... which concerns the nature of truth and whether it is purely logical and independent of man or whether it can only be defined relative to individual experience" (p. 305). It relates to the philosophical approach of investigating how the world should be seen and how the truth is supposed to emerge. This dimension has four levels:

1. **Axiomatic**: It is based in theorem-proofing, or 'scientific management principles' that assume a large knowledge *a priori* about the system;
2. **Logical Positivist/Empiricist**: It aims to isolate the phenomena from their context, when events are independent of their laws and theories;
3. **Interpretive**: It includes the phenomenon's context in the object of study. It focuses more on the meaning of events than on its facts;
4. **Critical Theory**: It combines the positivist and interpretive perspectives. Knowledge is placed in a higher context than its contribution to social evolution.

According to the authors, from levels 1 to 4, the research approach progresses from inductive to deductive, informal to formal, subjective to objective and creative to methodological. The higher levels imply a higher interaction with the environment and fewer initial assumptions.

The second dimension is the natural/artificial dimension. It relates to the sources and kinds of study data. Studies vary from empiricist, based in concrete data, to subjectivist, concerning the artificial reconstruction of reality. This dimension has three categories:

1. **Direct Observation of Object Reality**: This is the 'pure empiricism'. Phenomena are studied through direct observation of their environment or context;
2. **People's Perception of Object Reality**: Reality is expressed by the perception of individuals exposed to the phenomena. The investigator has no contact with the phenomena itself, but with people in its context;
3. **Artificial Reconstruction of Object Reality**: Reality is reconstructed in an artificial form to be more appropriate for testing and experimentation. Naturally, this approach needs the input of data collected under one of the two former approaches.

The more artificial is the level, the more the data collection is simple, efficient and easily controlled. These levels progress also from external validity search to internal validity, from small to large separation and from 'present' to 'past' data.

Easterby-Smith et al. (1991) indicated parameters of comparison related to the two previous frameworks. They compared design methods upon characteristics such as:

- The researcher is independent or involved (as in the second dimension above);
- Large samples or small samples (related to the scope of that second dimension);
- Testing or generating theories (as in Yin's first question);
- Experimental design or fieldwork methods (as in the second dimension above);
- Verification or falsification (as in the first dimension above).

5.3.3 The Choice of a Research Design Paradigm

Each design paradigm corresponds to specific types of research objectives and strategies. The selection of an appropriate paradigm depends on the comparison of their characteristics with those characteristics. On the appropriate selection of a research design depend in great extent the validity, generalisability and scope of the research.

Sections 5.3.1 and 5.3.2 presented the most common OM design paradigms and the parameters for their comparison. The choice of a paradigm for this study depends on their comparison with the characteristics of the study, as in Table 5-2.

Source	Yin (1984)			Meredith et al. (1989)	
Parameter Research Design	Research Question Type	Control over Events	Contemporary or Historical	Rational/ Existential Dimension	Natural/ Artificial Dimension
Experiments	how, why	yes	contemporary	empiricist	observation
Survey	who, what, where	no	contemporary	empiricist	perception
Historical Analysis	how, why	no	historical	interpretive	perception
Field Experiments	how, why	yes	contemporary	empiricist	observation
Action Research	-------	-------	-------	interpretive	observation
Case Studies	how, why	no	contemporary	interpretive	observation
Present Study	how, what	no	contemporary	interpretive	observation/ perception

Table 5-2: Research design paradigms and the present study

The characteristics of this study presented in Table 5-2 were discussed in the previous sections. This research aims to investigate the relationships between trade-offs, flexibility and capabilities. That leads to questions such as *how* one may deal with trade-offs and *what* is the role of flexibility and capabilities in this context. As this study focuses on industrial organisations, there will be *no control over events* and the collected evidence will reflect *contemporary facts*. The explanatory approach discussed in section 5.1.4 suggests that this study is essentially *interpretive*, as it focuses on relationships and events rather than factual theorem-proofing. Finally, given the explanatory and broad research scope, data will be gathered both from perceptual (interviews) and observational (field visits) sources.

Table 5-2 suggests that case studies are the most suitable paradigm for this study. It does not mean that other paradigms would be 'inappropriate', but only that they would require adapting some of this study's features. The action research method is excluded since it has an interactive and long-term perspective that conflicts with the nature of this study.

Given the objectives, characteristics and scope of this research study, the use of a ***case study*** design paradigm seems to be the best alternative. This follows the comparison of its characteristics with this study's features.

5.3.4 Multiple Case Studies

According to Yin (1984), case studies aim to investigate contemporary phenomena in their context. The boundaries between phenomena and context are not always evident. Case studies collect evidence from multiple sources aiming to gather all the data that may help on answering questions such as why determined decisions were taken, how they were implemented and what were their results.

Case study methods consist in single or multiple case studies. The choice between single and multiple case studies depends on the research study goals and the characteristics of the investigated phenomena. This study's choice is on multiple case studies because (1) they are regarded as more robust than single case studies; (2) this research aims to investigate phenomena considered 'usual' instead of 'rare' and (3) they are more appropriate for the type of theoretical generalisation that this research aims to provide.

According to Yin (1984) and Eisenhardt (1989), the process of multiple case studies consists in a sequence of activities, summarised in Table 5-3.

Step	Activities
1. Developing theory	Define research question; develop a priori constructs; review literature;
2. Selecting cases	Select cases; define data collection instruments;
3. Conduct case studies	Enter the field; collect data; use diverse sources of evidence;
4. Data analysis	Within-case analysis (individual reports); cross-case analysis (comparison between cases);
5. Shaping hypotheses	Replication (not sampling) logic across cases; search evidence for the origins of relationships;
6. Enfolding literature	Comparison with conflicting and similar literature;
7. Reaching results	Final report; theoretical conclusions.

Table 5-3: The process of Multiple Case Studies
Sources: Eisenhardt (1989); Yin (1984)

This study concerns the investigation of a **Multiple Case Studies** according to the process described in Table 5-3.

5.4 Field Work

The field work planning is the definition of aspects such as the number and type of sites to be accessed and the access procedures in each one. The quality of these choices is essential to the success of the research and to its validity and reliability.

Besides following the theoretical concerns of the study, the field work planning has to be flexible. Not always the researcher can access the number and type of organisations considered the most appropriate. Even when he does, the data collection process may be prejudiced by a number of uncontrolled factors. The researcher has to adapt the research design to such contingencies to maintain both its consistency and practical attainability.

5.4.1 The Number of Cases

The first decision in field work design concerns the number of cases to investigate. The researcher has to choose between accessing a large number of sites or focusing on a small group. The first strategy is here called cross-sectional, and the second, in-depth.

Cross-sectional strategies relate usually to descriptive studies aiming to investigate phenomena across a large number of organisations (Easterby-Smith et al., 1991). They relate usually to the 'who', 'how much', 'how many' and 'where' types of questions (Yin, 1984). The idea is to collect data from sites in different contexts to highlight common facts that may provide the evidence for the identification of 'true' phenomena.

However, according to Easterby-Smith et al. (1991), cross-sectional designs have at least two limitations. First, they are inappropriate to explain why and how a given correlation exists. Second, the range of variables that may be effectively investigated in cross-sectional designs is small. That means only few factors that may explain a phenomenon may be properly considered in the research scope.

In-depth designs relate to focused research strategies. They concern the investigation of a small number of sites to allow the study of a large number of factors in a broad scope. The contact between investigator and organisation is also more intense than in cross-sectional strategies. In-depth designs are appropriate for explanatory studies aiming to explain 'how' and 'why' things happen. They are thus best related to the second stage of Meredith's (1993) research cycle (explanatory), while cross-sectional design concerns the third stage (testing).

Given its explanatory character, this study grounds on the ***in-depth strategy***. It concerns the study of a small number of organisations on a broad range of variables relating to trade-offs, capabilities and flexibility. There are no strong hypotheses so far in the literature on the relationships between these subjects. The research is essentially in the descriptive stage that is the identification of variables and their relations. This study aims to advance this process to the second stage. This requires a broad type of investigation that can be best supported by an in-depth strategy.

5.4.2 Choice and Access to Case Sites

The appropriate selection of case sites has a major importance in studies aiming to build theory. It helps to determine the extent to which the research findings may be generalised and serve as a control barrier to external variations on these findings (Eisenhardt, 1989).

Explanatory case studies rely usually on the theoretical sampling of sites. Cases should not be chosen randomly, as in experiments. They should instead 'fill theoretical categories and provide examples of polar types.' (Eisenhardt, 1989). According to Platts (1993), the researcher should define whether to look for consistency in similar types of sites or test the feasibility of the general process in different sites.

The choice of case sites depends therefore on a trade-off between research validity and generalisability. However, if the number of sites granting access is small, 'availability' becomes the most important factor in this selection. The increasing amount of management research from inside and outside academy has been turning the access to organisations each time more difficult. Field research has become 'the art of the possible'. According to Buchanan et al. (1988), it means that an excessive tying of sites selection to methodological and theoretical concerns may turn it impossible getting access to the appropriate case sites. They stress that research studies should follow an opportunistic approach for an appropriate combination between theoretical concerns and practical availability.

This research focuses on manufacturing organisations sites. To allow the generalisability of findings within different manufacturing sectors, these sites should have different sizes and product types. The choice of sites is limited by this policy and their availability.

5.4.3 The Level of Analysis

The choice of the level of data collection depends on theory and methodology aspects. Section 2.2.4 discussed the levels of analysis of flexibility and that may be used here. Gerwin (1987) and Slack (1987) frameworks were summarised in the following taxonomy:

A. Resources' Level:
1. the individual machine
2. the individual function
3. the individual manufacturing process
B. System's Level:
4. the factory (manufacturing function)
5. the entire production system

Table 5-4: Levels of analysis of flexibility

The choice of the appropriate level of analysis depends on the trade-off between the number of variables to be considered and the depth of the investigation. Level 1, the individual machine, permits the most in-depth investigation type, but also offers a limited range of relevant variables. By increasing the level of investigation, the depth of the investigation decreases and the number of relevant variables increases.

One may also suggest that explanatory studies should concern higher levels than those of testing studies (unless the hypotheses in test refer to high level variables). If the variables of phenomena are still not properly identified, it is natural investigating then in a broader context than if they were already identified.

This study will focus on the ***factory's level*** of manufacturing companies (level 4). This decision follows the explanatory character of the study and the assumption that this level offers the best combination of depth and scope of the research subjects.

5.5 Data Collection

After defining *where* to collect data, the next step in research design is defining *how* to collect data. Business organisations are complex systems. The amount, types and sources of data they offer are almost unlimited. It is thus necessary to define *a priori* the sources and strategies of data collection in the field work.

This section discusses the aspects concerning the data collection process. It is divided in two parts, relating to the sources of evidence and the principles of data collection.

5.5.1 Sources of Evidence

Multiple case studies collect usually evidence from three sources: **records**, **observations** or **interviews**. Each source is more appropriate to specific research needs and contexts. The choice of sources of evidence depends on characteristics such as their availability, utility, authenticity and readiness for future re-examination or audit. Depending on these factors, the investigator can also decide whether focusing on one or multiple source types. This section discusses these sources of evidence, based on Yin (1984) and Flynn et al. (1990).

Records: The two basic types of records are *historical archives* and *documentation*. Multiple case studies use often records as 'secondary' sources to support the evidence from other sources. Common examples of records in OM studies are personal and organisational records, administrative documents, news-clipping and reports of events. The access to records is usually simple and depends on the organisation's approval. Their major advantage is that their data are usually unbiased, since their purpose is other than the research (Flynn et al., 1990). However, this also means that the researcher has often to adapt their structure to the research needs.

Observation: Observation methods consist in outside and participant methods. Outside observation is a passive method - the researcher only *registers* relevant events and facts. In participant observation, the researcher engages in the process and influences the events. The major advantage of outside observation is that it may be more casual and flexible than participant observation. However, participant observation may provide more valuable data than outside information, since the researcher has probably a better understanding of the context as well as organisation's support. Just like records, observation data may be useful as primary evidence and as corroboration for other data. It is a good method in OM studies, specially concerning shop floor activities.

Interviews: Research interviews are divided into structured, focused and open-ended types. Structured interviews consist in 'closed' questionnaires similar to those of surveys. Because of their pre-structured nature, closed questionnaires are usually inflexible in coping with unanticipated needs such as collecting additional data or focusing on subjects out of their scope. They are more appropriate to research studies relating to the first and third research stages (descriptive and testing) than to explanatory studies.

Focused interviews are more flexible than structured interviews. They follow semi-structured questionnaires that guide the interviewing process along basic questions. The researcher may extend the inquiry to other questions or subjects not anticipated. According to Yin (1984), focused interviews may be open-ended and conversational, yet they are relatively well structured.

Finally, open-ended interviews are not pre-structured and are very flexible, covering a scope of subjects as large as needed. Respondents are expected to freely narrate and describe events and facts relating to specific phenomena. They may express their opinions about these facts, suggest sources of additional data and propose talking about other subjects that may be relevant.

Conclusion: The appropriate choice of sources of evidence is a key success factor of research studies. Different sources relate better with specific research types (descriptive, explanatory, testing), uses of data (primary data, corroboration) and natures of subjects (historical, contemporary, comparative). Not always the investigator can access the type and amount of data desired. Flexibility and creativity are two determinants of his success.

According to Eisenhardt (1989: 537), "theory-building researchers typically combine multiple data collection methods". It is often interesting combining different types and sources of data. This strategy has always been 'instinctively' common in social and natural sciences and has been formally defined in the concept of triangulation[2] (Jick, 1979).

This research data collection will be based on ***focused (semi-structured) interviews and outside observation***. These methods are the most appropriate for this research's questions and strategy. These and other research design aspects will be further discussed in chapter 6.

5.5.2 Principles of Data Collection

Generalisability and validity are the two key attributes of study data. They depend on both the prior qualities of the data and the procedures in their collection. These may be maximised if one follows some principles in the data collection process. Yin (1984) suggested that three principles must guide the data collection process in this purpose:

Using multiple sources of evidence: The use of single sources of evidence is usually adequate in case studies. However, using multiple sources may help the researcher to address a broader range of issues and to enhance the study's validity. The value of a finding increases when corroborated by data from other sources (Yin, Bateman and Moore, 1983).

[2] Although this concept is even broader, since it advocates the combination of not only different sources of evidence, but even of different research *approaches* (quantitative and qualitative).

Creating a case study data base: The study's reliability increases if the investigator creates a case study data base. The data base is not a report, but a repository for the rough data collected in the sites. These data may be retrieved if necessary by people interested in replicating or assessing the study. The data base keeps rough data such as notes, documents and narratives as they were before their interpretation and analysis.

Maintaining a chain of evidence: Building a chain of evidence aims to inform about the links created between data and conclusions. This is reporting details such as the sources of each data and the circumstances in which data was collected. The chain of evidence permits other people to trace the process linking data collection, analysis and conclusions.

Eisenhardt (1989) also addressed these principles. They will be further discussed in the following section.

5.6 Data Analysis

Data analysis is the critique and reporting of collected data and its comparison with the study's assumptions and propositions. The literature on data analysis is less extensive than on previous subjects. The data analysis in multiple case studies has usually three stages: (1) a series of individual 'within-case' analysis, (2) tracing 'cross-case' comparisons between the individual sites and (3) shaping the hypotheses that may explain the manifested phenomena and answer the study's research questions (Eisenhardt, 1989; Yin, 1984).

One may induce the research data analysis and conclusions by alternative 'models of analysis'. These alternatives are appropriate to different case study types (exploratory, explanatory or descriptive). The study reliability depends in part on the appropriate choice of a mode of analysis.

According to Yin (1984), the most appropriate mode of analysis to explanatory studies is the 'explanation-building' logic. The study should 'explain' the cases through the relationships and links found among their elements. This explanation requires series of interactions between the initial hypotheses, data, additional data and literature.

5.6.1 Within-Case Analysis

Within-case is the first step in data analysis. It consists in writing-up each case study to organise the usually large amount of data collected. Because of the amount of data and their usual uniqueness in format and content, there is no formal procedure, or 'best pattern' suggested for the within-case writing-up (Eisenhardt, 1989). Data analysis methods to be used in this study's within-case include clustered matrices, structured displays of subject, case dynamics matrices and relationship networks (Miles and Huberman, 1994).

The process of within-case analysis has some common pitfalls. The most usual is the attempt to build extensive narratives with low density of useful data such as reporting interviews, meetings and shop-floor visits. The second mistake is creating a large number of categories to accommodate any type of quantitative data collected, also deviating from the study focus. The third problem is on choosing the correct path to build explanations.

Yin (1981) suggested some ways to avoid these problems. First, the investigator should distinguish 'note-taking' from 'narrative-writing'. Narrative accounts should focus on the major and substantive topics of the case study. The investigator should *take notes* during the data collection to be later translated into meaningful and essential reports organised around specific questions or activities. Martin and Turner (1986) stated that good notes are often more meaningful than extensive reports. Second, and following the first technique, 'the quantitative data should reflect meaningful events' that is focus on the basic research subjects. Finally, explanatory case studies should be in three steps that are (1) the summary and interpretation of facts, (2) building alternative explanations for the facts and (3) reaching conclusions reflecting the explanations that seem most appropriate. The within-case analysis of case studies should be based on these techniques.

5.6.2 Cross-Case Analysis

The second step in data analysis is the cross-case search for patterns. The cross-case analysis compares the data from different sites so that perceived similarities and differences may lead to the building of conclusions. According to Eisenhardt (1989), some mistakes may be easily committed in this analysis, leading to premature or false conclusions. She suggests these mistakes may be avoided by using tactics such as:

1. Defining categories of comparison (such as matrices 2 x 2) to look for within-group and inter-group similarities and differences. These categories may originate from the research problem, literature or data;
2. Selecting pairs of cases and listing their perceived similarities and differences. Finding similarities in seemingly different cases or differences in apparently similar cases may help on identifying new categories, ideas and explanatory hypotheses;
3. Classifying data according to their sources. This tactic assumes that, by corroborating data of different sources, one may get stronger and more grounded findings (see section 5.5.2). That means collecting evidences for specific facts in different sources such as interviews, observations and questionnaires.

Data analysis methods to be used in this study's cross-case include case ordered displays, 2 x 2 matrices and variable by variable matrices (Miles and Huberman, 1994).

5.6.3 Shaping Hypotheses

The final step of the data analysis is the building of theory relating to the study's objectives. This is the research findings or conclusions. The shaping of hypotheses combines the results of the within-case and cross-case analyses with the impressions and beliefs of the investigator and the current literature. The process of generating new theory from data is interactive (Eisenhardt, 1989).

The shaping of hypotheses follows two steps that are sharpening constructs and verifying the congruence between these constructs and data evidence. The sharpening of constructs consists of (a) refining the definition of constructs through constant interaction with data and (b) defining measures to evaluate their validity. Differently of hypothesis-testing research, case studies attempt to build these concepts and measures *after* the data analysis process. The second step is testing the new hypotheses with each case's evidence. Cases that confirm the hypotheses empower their validity. Cases that do not confirm the hypotheses provide the evidence for their refinement or extension. Qualitative data are particularly useful to evidence why a given hypothesis may be or not supported by a specific case (Eisenhardt, 1989).

The data analysis process of this study will have these three stages (within-case analysis, cross-case analysis and shaping hypotheses). It should follow ideas and recommendations discussed above.

5.6.4 Data Analysis Report

The data analysis process ends with writing-up the case studies report. This report presents the major collected data and its analysis, aiming to strength the study generalisability and validity. The major decision here is on the choice of a structure for the report. The structure should follow the type of data and results to be driven by the research. Yin (1984) suggests three alternative types of data reports to multiple case studies. These are the narrative type, the question-answer type and the cross-case type.

The narrative type consists in a report of several parts, each one relating to one site. Data are often presented with auxiliary displays such as tables and figures where necessary. A final chapter concerns the cross-case analysis.

The question-answer type is more objective. As it name says, this report consists in the presentation of data as answers to specific research questions. The major advantage of this method is that it states clearly the major research questions and answers and how these are linked with the research conclusions.

The final type focuses on the cross-case analysis rather than on the within-case. Each chapter or section describes or explains a specific part of the cross-case analysis. The information of each case is dispersed along these chapters. This structure is particularly adequate to studies aiming to emphasise the cross-case analysis rather than the single cases.

Above all, the case study report must be well structured. According to Yin (1981), lengthy narratives are usually confuse and difficult to read. The researcher should focus on building an objective and well-organised report. The quality of the data analysis report relies on (1) the appropriate choice of its structure, (2) its clarity and (3) the quality of its content.

The researcher believes that the narrative type of report is the most adequate for this study. The study regards major importance to the individual case studies. This series of within-case narratives will then be followed by a cross-case comparison of the different cases.

5.6.5 Section Conclusions

The process of gathering and analysing data has a linear component, but is essentially interactive. The investigator has to constantly (1) refine the hypotheses and findings using the evidence provided by data and (2) refine the data collection after these new hypotheses and findings. This process should lead to a high correspondence between theory and data, strengthening the validity the research findings. The validity also depends on the necessary comparison between research findings and the literature.

As Eisenhardt (1989) pointed out, the key questions at the end of the data collection and analysis are when to stop adding cases and when to stop the interaction between theory and data. The moment for stop adding cases is when the cost of collecting additional data becomes higher than the benefits of the information they provide. The interaction between theory and data also has also a point of saturation, when not many additional ideas can be added to the results and conclusions of the study.

5.7 Chapter Conclusions

This chapter discussed the main aspects on the methods for this research. It focused on six major subjects that are the OM research, quantitative and qualitative approaches, research design, field work, data collection and data analysis. It presented and analysed alternative strategies relating to each aspect to ground and justify the decisions on research design.

Section 5.1 presented the main research models, concerns and strategies of today's OM research. This study has an empiricist, broad scope and knowledge oriented character. It will build theory based on explanatory and bridging strategies, linking the theory of trade-offs, capabilities and flexibility to extend the knowledge about trade-offs.

Section 5.2 discussed the use of quantitative and qualitative approaches in this research. The qualitative approach is the best related to this research. This implies an involvement between investigator and subject, the analysis of facts in their context and the independence of results from prior theoretical prepositions.

Section 5.3 discussed the choice of a research design paradigm. It presented several design paradigms with their parameters of comparison and choice for this study. This study will ground on multiple case studies to investigate contemporary events under an interpretative manner, evolving observations and people's perceptions sources.

Section 5.4 discussed the field work. This research will investigate a small number of manufacturing organisations. It will attempt to generalise its findings by researching organisations from different industries and sizes. The choice and access of case sites are based on these premises and on the actual availability of offers of access.

Section 5.5 discussed the data collection process. This research attempts to gather data through focused interviews supported by a semi-structured questionnaire and through outside observation. The use of multiple sources of evidence and the maintenance of a chain of evidence along the data collection and analysis will characterise this process.

Finally, Section 5.6 discussed the data analysis process. This will have three stages: (1) the within-case analysis of sites, (2) the cross-case analysis of the similarities and differences among sites and (3) the shaping of hypotheses leading to the results and conclusions. Table 5-5 summarises the major decisions on the methods and design of this research:

The aspect	is characterised by
Research proposition	Empiricism, broad scope and knowledge orientation
Research strategy	Explanatory and bridging strategy
Research results	Building theory (framework)
Research approach	Qualitative method
Design paradigm	Multiple case studies
Field work strategy	In-depth study
Field target	Manufacturing companies
Data collection sources	Focused interviews and outside observation
Data collection instruments	Semi-structured questionnaire and field notes
Data analysis method	Within-case, cross-case and shaping hypotheses

Table 5-5: The major decisions on the research design and methods

Chapter 6 - Research Design

Chapter 6

Research Design

Introduction

Chapter 6 discusses the aspects relating to this study's data collection process. It translates the methodological objectives defined in Chapter 5 into operational decisions. These decisions concern the choice and access to the case sites and the definition of the data collection instruments.

This chapter has two sections. Section 6.1 discusses aspects on the choice and access to the case companies and interviewees and the sources of data. Section 6.2 focuses on the major data collection instrument to be used in this process. This instrument, a semi-structured questionnaire, is designed to support the interviews - one of the sources of data from the companies.

6.1 The Data Collection Process

This section discusses the decisions on the choice and access to case sites, the choice of interviewees in each site and the sources of data to be assessed in this process.

6.1.1 The Choice of Companies

The choice of the group of companies to serve as case sites is not random, but planned. Such approach is in the core of the case studies theory. It aims to provide the researcher with meaningful cases able to, according to Eisenhardt (1989: 537), "... fill theoretical categories and provide examples of polar types." The basic decision here is on the criteria of this choice. The researcher has to define whether to investigate similar types of sites (looking for differences in the cross-case analysis) or different types of sites (looking for similarities in the cross-case analysis). This involves a trade-off between research validity and generalisability.

The choice of this study's case sites depends on this trade-off and on their availability to access. This study focuses on 'manufacturing companies of varying sizes and product types'. The author believes that this is the choice providing the best combination of generalisability (from varying size and product types) and validity (from repeating manufacturing companies) to the study.

The second decision is whether to access only British companies or a mix of British and Brazilian companies[1]. The second option is preferred for the following reasons:

- A mix of companies from distinct competitive environments should provide a more extensive, varied and polar range of data than the same number of companies from a single environment. The economic, social and competitive context of Brazil is different from that of Great Britain and those differences should be partially reflected in these data[2];
- This variety of data enhance the generalisability of findings, since they refer to more than one socio-economic context;
- The validity of similarities between companies in different countries is greater than that between companies in a same country. Differences between these cases may be discriminated according to their origin (internal or external to the companies), since more than one company should be assessed in each country.

The third question concerns how many companies to contact in each country. Given the objectives of this research, its explanatory and in-depth character and the number

[1] This follows the opportunity to access companies in Brazil, where the author comes from.
[2] Prochno and Correa (1995) stressed some of the economic and industrial markets characteristics of Brazil that may enhance the value and variety of evidences from that context.

and extent of issues involved, the research believes that at least two and no more than three companies should be assessed in each country. Accessing two companies from the same country permits the discrimination between internal and external sources evidence. Accessing more than three companies in each country would limit the researcher's ability to spend the time and resources that are necessary to properly investigate each organisation.

6.1.2 The Access to People

The choice of people to consult in each site depends on three aspects. The first is the decision level relating to their activities. This depends on the level of the study. The second is the organisations' area relating to these people. This depends on the subject in study. The third is the number of people to access in each site. This depends on the chosen area and level, company size, availability and variety of data to collect. In case studies, the type of data provided by different individuals may vary or not (Yin, 1984).

As discussed in Chapter 5, this study focuses on the factory's level of manufacturing companies. That is a pre-identified system focused on a specific set of products. Naturally, the size of this 'factory' may vary - and should vary - across different sites. This study thus concerns contacting managers relating to the factory's level. Depending on the size of the factory, the actual designation of these people's jobs may vary - names such as manager, director or supervisor are expected - but the crucial aspect is the scope of these people's activities.

These managers should relate to the OM area. Operations managers are the people with the best understanding of the subjects in study. In practice, this may represent areas such as production, fabrication, engineering or even 'related' areas such as production planning, project or general management.

The final decision concerns how many people to access in each site. This depends, among other things, on the size of the company, the people's availability and the level of centralisation of management.

6.1.3 The Sources of Data

This study grounds on two major sources of data. The first is outside (non-participative) observation of activities in the shop-floor. This aims to gather data on aspects such as the companies operations, impact of trade-offs on the shop-floor and 'informal' views of operators and other people on trade-offs and other subjects.

The second source of data is interviews with operations managers. These interviews are supported by a semi-structured questionnaire to support an *open-ended, conversational process*. The questionnaire contains the essential questions to be made but also allows extending the inquiry to other subjects not anticipated but relevant.

Depending on the context of each organisation, additional sources of data such as documents may also be considered. The data collection process is obviously flexible and should be able to collect the quality and quantity of data that may provide the necessary understanding of the research subjects.

6.2 The Research Questionnaire

This section discusses the questionnaire to be used with the case sites interviews. The objective of defining such questionnaire is to guarantee that some fundamental questions should be equally addressed in all the case companies. Most of these questions should lead to open, explanatory conversations on additional facts or subjects. The structure of the questionnaire reflects the structure of the whole data collection process. Hence it seems valid at this point to discuss these questions. A sample of the questionnaire is in appendix.

6.2.1 General Structure and Objectives

The questionnaire contains ten questions along four sections relating to specific subjects and propositions. Each section starts with some closed, 'restrictive' questions and ends with some open, explanatory question. This is to conduct the interviews through a series of statements and explanations, where the statements are the identification and/or qualification of issues and the explanations are the interpretation and correlation of different issues. The first three sections concern the major study subjects, correspondingly, (1) manufacturing objectives and trade-offs, (2) flexibility (resources and capabilities) and (3) production capabilities. The last section investigates the relationships among these subjects. Figure 6-1 illustrates this structure and objectives.

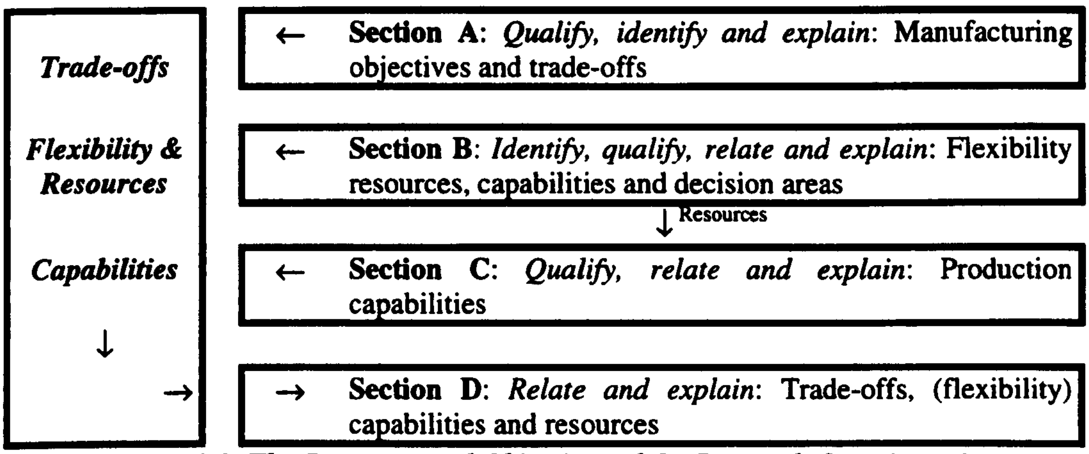

Figure 6-1: The Structure and Objectives of the Research Questionnaire

6.2.2 Questionnaire Sections and Questions

This section discusses each of the four sections of the questionnaire. It presents the questions and discusses the objectives and strategy of each section.

Section A - Manufacturing Objectives and Trade-offs

Section A concerns the identification, qualification and explanation of manufacturing objectives and trade-offs. It has three questions:

1. What are the competitive importance and performance of these following manufacturing strategic objectives in your company today? How were then five years ago (or later: _______ (mm/yy))?
2. Can you indicate which of these (following) trade-offs between those objectives happen in your plant? How important are they?

3. Concerning the most important trade-offs: Can you give an example of each trade-off as in practice? If management tried to eliminate it, how was it and how successful was this attempt?

The first question qualifies the importance and performance of objectives relating to the five MSDs[3] (cost, quality, flexibility[4], speed and dependability) in the present and past. This question introduces the idea of manufacturing objectives to support the following assessment of trade-offs between these objectives.

The second question asks for the identification and qualification of trade-offs between MSDs. It shows the ten possible trade-offs between these objectives and asks to identify which ones 'happen' in the system and what is their importance.

The third question is an extension of the second. It explores the trade-offs considered most important. The interviewee should explain how these happen (with examples) and how OM deals with then.

The first section introduces major research questions: whether and how trade-offs happen and how one deals with then. The next sections concern proposed solutions to this problem.

Section B - Resources and Flexibility Capabilities

Section B concerns the identification and qualification of flexibility resources and capabilities. It also investigates the impact of improving resources in flexibility capabilities and decision areas. It has three questions:

4. (a) Have some of these (following) technologies or methodologies been implemented in this plant in the last five years? If so, could you please indicate when the implementation started and finished? (b) Can you specify which (following) manufacturing decision areas were most directly affected by the introduction of these technologies and methodologies?

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[3] These are the 'generic' objectives relating to each MSD.
[4] Later changed to variety - see Chapter 7.

5. How good is the competitive performance of these flexibility capabilities now and how were they five years ago (or later: _______ (mm/yy))?
6. Concerning the most important cases above: Can you explain how has a specific improvement affected the performance of a specific flexibility capability?

Question 4 has two parts. It first presents a list of resources and asks to indicate those that have been implemented in the site. The list of resources is primarily extracted from the literature on flexibility. However, given the scope of these technologies and methodologies and the opportunity for the indication of other types (in items 10 and 16), *this may be considered a list of 'generic' resources*. The second part asks to indicate the impact of these new resources in different manufacturing decision areas to help the establishment of relationships between resources and capabilities (since capabilities relate to specific areas).

Question 5 concerns the performance of flexibility capabilities in the present and past and the impact of resources in their performance. The list of suggested flexibility capabilities is derived from the literature in Chapter 2. It is impossible to provide a list of capabilities to fit each case *a priori*. However, this list attempts to be as comprehensive as possible. The interviewees can also suggest other origins for changes in performance rather than those resources.

Question 6 is an exploratory question asking to explain and exemplify how the resources affected the performance of flexibility capabilities as suggested above.

Section B aims to identify, qualify and build relationships between resources and flexibility capabilities. This first level of relationships (to be completed in the next section with the introduction of generic capabilities) should lead to the establishment of relationships between trade-offs, capabilities and resources in section D.

Section C - Production Capabilities

Section C is the qualification of the performance of production capabilities and the evaluation of the impact of new resources in that performance. It has two questions:

7. How good is the competitive performance of these capability measures now and how were they five years ago (or later: _______ (mm/yy))?
8. Concerning the capability measures that have changed: Which technologies or methodologies (#) have affected their performance? Can you explain how it happened? Which activities most affect these measures?

Question 7 presents a list of performance measures of capabilities relating to the remaining (after flexibility) MSDs: quality, cost, speed and dependability. It asks to qualify each of these measures in the present and past. There are three reasons for the listing of performance measures instead of production capabilities here. First, it is easier for an operations manager to understand and qualify a performance measure than a capability. Second, it is expected that a range of 'n' performance measures can be more comprehensive than a range of the same size of production capabilities. Third, and related to the second one, it is easier providing a list of performance measures to suit all the case sites than a list of production capabilities with that purpose. Performance measures are more generalisable than production capabilities.

Question 8 is the exploratory question in this section. It identifies which resources affected those measures and how. It builds primary relationships to lead to the final ideas in section D. The last part of the question asks activities (capabilities) best related to the measures assessed in this section. This aims to close the gap created in question 7 between the ideas of performance measures and capabilities.

Section C qualifies the production capabilities and relates their performance with the resources provided in section B. It is the final step before the major questions are addressed in section D.

Section D - Trade-offs, Capabilities and Resources

Section D is the final and main section of the questionnaire. It concerns the building of relationships between resources, (flexibility) capabilities and trade-offs. It investigates the factors that affected the trade-offs performance and how it happened:

9. What was the impact of the new resources in the performance of trade-offs? Was this impact negative (that means the trade-off became more strong), neutral (or 0, that means the trade-off did not change) or positive (that means the trade-off became weaker or was eliminated)?
10. For each trade-off that has changed, can you indicate which of the following variables were most influential in this change? ***A)*** An improvement in some flexibility capability, changing the nature or the environmental conditions of this trade-off. If so, please explain in which cases it happened and which improvements and flexibility capabilities were involved. ***B)*** Another factor or capability. If so, please explain how and where it happened and which improvements and factors are involved.

Question 9 investigates the relationships between trade-offs from section A and resources from section B. It verifies whether one can establish relationships between these concepts and, specially, examines whether these relationships are direct or indirect. The examination of whether a relationship is direct (that is resources → trade-offs) or indirect (that is resources → capabilities (or other variable) → trade-offs) is made by asking for an example of this impact. If this relationship is indirect, section 10 will identify that intermediary element.

Question 10 thus explores the nature of those relationships. One should indicate which elements of the system affected the changing trade-offs and how. Following the strategy of the study, it emphasises the role of flexibility capabilities (in option 'A') but admits any other variable as a source of improvements (in option 'B').

Section D closes the questionnaire, aiming to establish whether and how trade-offs have been improved in the case sites and which relationships may be defined between trade-offs, resources, capabilities and flexibility.

The questionnaire will be used in the interviews with operations managers in an open-ended, flexible manner. Its aims to introduce the debate of specific points that can then be further discussed according to the opportunities and needs of the situation. Its major aims are to (a) clarify to the interviewees the points to be discussed and (b) ensure that similar subjects are covered in the different interviews.

6.3 Chapter Conclusions

This chapter discussed the data collection process defined for this study. The first part discussed the choice and access of case sites. The second part presented the questionnaire to be used as part of this process. The major definitions regarding the choice and access of case sites are:

1. This research will focus on manufacturing companies of varying sizes and product types. At least four companies should be assessed: two Brazilian and two British;
2. The data collection process will consist in visits to the shop-floor, interviews, informal talks and individual or collective meetings with people from the sites;
3. Formal interviews should be made with all the major operations managers of each site. These people should have an understanding of the entire operations system.

The research questionnaire has ten questions along four sections. The first three sections look for the identification, qualification and establishment of basic relations between the subjects. The last section links these subjects and establishes whether and how one can manage manufacturing trade-offs.

Figure 6-2 summarises the data collection process. This setting follows the multiple number of data sources to be used in these investigation. The steps are interactive, that is, data collected in one step of the investigation should be related with the remaining data and the results of one step may get the researcher back to a previous step.

Summary of Data Collection Process

Step	Action	Sources of Data	Types of Questions
1	Visits to shop-floor	Observations Documents	What, How
2	Informal talks	People's perception Documents	What, How
3	Individual or collective meetings	People's perception	What
4	Interviews	People's perception Questionnaire	What, How, Why
5	Additional visits or phone calls	Any previous sources	How, Why

Figure 6-2: The data collection process: Summary

Part III - Data Analysis

Part III is about the analysis of the data collected in the case companies. This is in two stages. The first stage concerns the analysis of each company as individual. It combines the data from different sources into one single context, aiming to discuss the major aspects of that company that may influence this research. The second stage concerns the comparison of the data from different companies. It aims to highlight the major similarities and differences between these companies to ground the building of propositions at the end of the research. Part III is divided into two chapters:

Chapter 7

Within-Case Analysis

Chapter 8

Cross-Case Analysis

Chapter 7 - Within-Case Analysis

Chapter 7

Within-Case Analysis

Introduction

This chapter presents the within-case analysis of data collected in the case sites. The within-case analysis is an interpreted summary aiming to organise, present and draw conclusions on those data. The data referring to the case companies were provided by three major sources: (1) observations of shop-floor activities combined with 'informal' inquires; (2) interviews with operations managers[1] and (3) documents and papers provided by the companies and by secondary sources[2].

Each within-case is a case study. The structure of the case studies follows a pre-analysis of data and ideas from the literature and research framework. The framework for the first part is presented in Figure 7-1 and should be improved after the findings discussed in Chapter 9. Each within-case analysis starts with some background information on the companies' strategy and shop-floor structure. The cases are then presented along the following aspects:

a) **Manufacturing trade-offs.** This is the identification of abstract issues on trade-offs in the site. It concerns the following aspects:

- **General view**: This concerns the concepts that people might attribute to trade-offs, such as compromises between MSDs or inter-departmental conflicts; their ability to understand the idea of trade-offs; whether they considered trade-offs existent or not; whether they saw trade-offs as relevant to OM and strategy; whether these ideas were uniform or variable across the organisation, etc.;

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[1] All interviews were recorded, albeit the companies names were concealed. The validity of statements made in these were usually checked by either asking for examples and/or further explanation or cross-examining those data with the evidence from other sources. Data about the companies' background were collected either in the first meeting with operations managers or during the outside observations.
[2] Since the companies required their names not to appear here, no references are made to these sources.

- **Nature of trade-offs**: This concerns the major characteristics of trade-offs, as perceived by the researcher and by the individuals. They might be characterised as dynamic or static; as deterministic or contingent on external and internal system's variables; as possible to be eliminated or as having a limit for improvement; as related with other trade-offs or not;

- **Importance factors**: This is the identification of the variables that seemed to determine the level of importance of trade-offs in the case. Importance factors always related to the cases' MS and competitive environment. Single factors could affect one or more trade-offs; single trade-offs could relate to a number of factors. The importance of a trade-off is its impact on MS and competitiveness;

- **Performance factors:** This is the identification of the variables that seemed to determine the performance of trade-offs in the case. Performance factors always related to the cases' resources, capabilities and attributes[3]. Single factors could affect one or more trade-offs and single trade-offs could relate to a number of factors. The performance of a trade-off is its strength;

- **Effects on OM and strategy**: This is about the ways that trade-offs seemed to affect the system's performance, management and competitiveness;

- **Management of trade-offs:** This is about the ways that OM dealt with trade-offs. It summarises their approaches and beliefs on adapting and/or improving major trade-offs, aiming to characterise the types of strategies employed.

General View

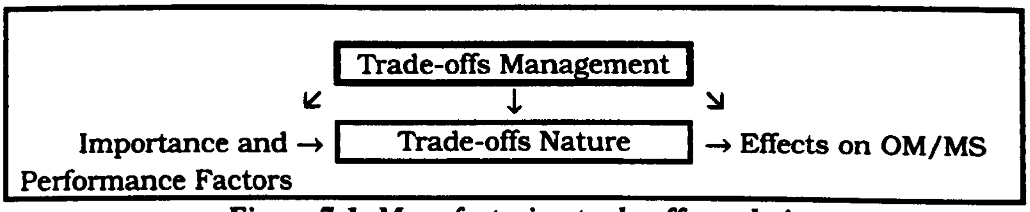

Figure 7-1: Manufacturing trade-offs analysis

b) Major manufacturing trade-offs. This is the identification of concrete issues on the major trade-offs in the site. This section focuses on the most important trade-offs

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[3] Resources and capabilities were defined in Chapters 1 and 4. Attributes measure the 'internal' performance of resources and capabilities. They concern variables such as flexibility, reliability, co-ordination and capacity. They are further discussed in the following chapters.

in the site, i.e. the ones that had a major impact on OM and strategy. It relates to the following aspects:

- **Shaping**: This is the description, justification and/or example of each of the most important trade-offs in the site. It aims to characterise the major characteristics of the trade-off and explain how and why this occurred;
- **Managerial approaches:** This discusses the ways that OM dealt with the trade-off - strategies, actions and objectives in its management - and the impact of these actions on the performance and/or importance of the trade-off;
- **Performance factors:** This describes the resources, capabilities and/or process attributes relating to the management of the trade-off; how and why they were affected by OM actions and which effect they had on the trade-off.

c) Manufacturing flexibility and trade-offs. This describes the relationship between flexibility and trade-offs in the site. It concerns the following aspects:

- **Flexibility types:** This is the identification of the types of flexibility that seemed to relate to the management of each of the company's major trade-offs;
- **Relationships between flexibility types and trade-offs**: This describes the way that flexibility types seemed to affect the trade-offs; what was the nature of the impact of these (changing) flexibility types on the trade-offs;
- **Flexibility capabilities and resources**: This describes the major resources and capabilities that seemed to base the improvement of each flexibility type and therefore the changes in relating trade-offs. It also discusses how these increasing resources and capabilities affected the flexibility types.

7.1 Case A - The British Mechanical Equipment Manufacturer

7.1.1 Company's Background

<u>**Strategy**</u> - Company A was a mechanical equipment manufacturer located in the West Midlands, England. This site was one of the three units of the firm in the UK. The

firm had manufacturing plants, sales offices and distribution centres spread world-wide. It was founded in the early 1910's in the USA - where its matrix was located - and employed about 54,000 people world-wide. This unit employed around 1,100 employees - 50% in the shop-floor and 50% in the office.

This plant assembled a large variety of mechanical equipment mainly used in civil engineering. The shop-floor consisted in three production lines. Each line focused on one product family. Products from line A corresponded to 35% of the production value, products from line B corresponded to 50% and products from line C corresponded to 15%. Each family had a major 'typical' product with many variations.

The company usually assembled-to-order, in spite of some best-selling units of line B were assembled-to-stock. It had a network of dealers in the UK (about 100) and world-wide. The assembly-to-order process started with dealers receiving customised orders from customers. Dealers then sent orders to the company that assembled matching products. Products were delivered to dealers and then to customers.

Parts assembled in there were either made in other units of the company or in third-parties. About 20 suppliers corresponded to 90% of the purchasing value. About 50% of purchases came from the UK, 30% from Europe and 20% from other countries. The turnover in 1995 was near 200 million sterling pounds and increasing. Sales were 10% to the UK, 70% to Europe and 20% to other countries.

There were four levels of management in the UK and 2 more top levels in the matrix. The strategy formulation process comprised the company divisions - this site was part of a division for the UK and one other European country. There was a 5 year competitive strategy revised annually. The company mission concerned (1) quality (products reliability), (2) products variety and (3) dependability.

<u>**Shop-Floor**</u> - This site had been operating for over 30 years. It employed diverse advanced technologies, specially for production scheduling (computer aided process planning), inventories control and materials handling (automatic stalkers) and parts

transportation (automated guided vehicles). There were about 550 employees in the shop-floor, distributed along 3 assembly lines.

Each line focused on one product family. The lines were organised as a group of sub-assemblies (assembly cells - with the parts moving through) and one final assembly with a fixed layout.

The company had been implementing a number of work methodologies with relative success. Team-working and quality groups seemed to be operating well, and the operators had a fair degree of autonomy.

Two people were interviewed in this case: the Engineering Manager (M1), responsible for one of the assembly lines and the Design Engineering Manager (M2), responsible for product development. The data collection was in March-April 1996.

7.1.2 Manufacturing Trade-offs

General View - M1 and M2 **saw trade-offs** as compromises between alternative performance objectives. They were **relevant** because this company aims to compete in different dimensions that managers believed are not compatible. Except for CS[4] and CD in M2 view, they considered all trade-offs suggested as **existent**. The most **important** trade-offs related to the most important dimensions.

Nature - A **dynamic** approach to trade-offs characterised this case. Examples of this view are *"Quality and speed is still a trade-off, but I would say it has improved."* (M1) and *"We can have good quality for a better cost than we had in the past"* (M2). It does not mean that all trade-offs are bound to change: *"... I don't see them (QD) as less a trade-off than they were before"* (M1). Changing trade-offs requires changing the environmental factors that influence their performance and importance.

[4] Acronyms for trade-offs follow the initials C (for cost), Q (for quality), V (for variety), S (for speed) and D (for dependability). CS, for example, is the trade-off between cost and speed.

In spite of this dynamic view, managers doubted trade-offs could be improved to the point they would be **eliminated**. According to M1, *"Some things you can get to the point where you can put improvements and make them less a trade-off but, to get then to be independent, that is quite an achievement."* M2 saw a **limit to the improvement** of one dimension as related to another: "*... (there is one point when) we have to stop because we will not sacrifice quality.*"

As well as dynamic, trade-offs seemed **contingent**. This means (1) their levels of performance and importance depend on (variable) environmental factors and (2) the extent to which trade-offs can be improved varies from system to system. The contingency and dynamic were summarised by M1: *"This (the idea of trade-offs) is perceived both in shop floor and management and we accept that this is the reality for the time being and will be until our process improves and our capacity increases."*

Importance Factors - The importance of a trade-off is its significance to the company's competitiveness. In Case A, the importance of trade-offs depended on (1) the importance of variables as independent and (2) the nature of their relationship. Importance factors determined the importance of variables both as independent and as part of trade-offs.

Table 7-1 summarises the importance factors relating to specific trade-offs in Case A.

Importance Factor	Trade-offs Affected
Volume of demand	Quality x Speed Cost x Speed
Customer expectations	Quality x Speed Quality x Cost
Competitive priorities of the firm	Quality x Speed Quality x Cost

Table 7-1: Trade-offs importance factors in Case A

For example, if demand was high, a trade-off such as QS might have a strong impact in sales (since any quality failure should affect speed and thus lose sales deliveries). This should not happen if the demand was low, since the spare capacity should then cushion any delay caused by quality failures.

As Table 7-1 shows, the **three importance factors** provided in Case A concern **market and strategic variables**, always relating to the **external environment**.

<u>**Performance Factors**</u> - The performance of a trade-off is the combined importance of its variables. Trade-offs with **low** performance (1) are difficult to deal with, (2) limit the system's global performance and (3) have negative effects on the system's management and strategy (discussed later). Trade-offs with low performance are strong trade-offs.

It is suggested here that the performance of a trade-off is determined by a set of performance factors (not defined *a priori* in this research). Table 7-2 summarises the performance factors relating to specific trade-offs in Case A.

Performance Factor	Trade-offs Affected
Process reliability	General
Production capacity	General
Co-ordination (design teams)	Quality and Cost, Quality and Dependability
Product flexibility	Quality and Cost, Quality and Speed
Programming flexibility	Quality and Cost
Labour flexibility	Quality and Cost, Quality and Dependability, Quality and Speed
Process flexibility	Quality and Speed
Mix flexibility	Quality and Speed
Quality of supply materials	Cost and Dependability
Supply management	Quality and Speed, Quality and Dependability
Forecasting	Quality and Speed
Production abilities	Quality and Cost, Quality and Dependability
CAD system	Quality and Dependability
Workforce skills	Quality and Speed
Layout	Quality and Speed

Table 7-2: Trade-offs performance factors in Case A

For example, improving labour flexibility might improve the quality performance with no additional cost, thus improving this trade-off performance.

Table 7-2 contains **fifteen performance factors**, relating to system's **attributes** (e.g. reliability), **process capabilities** (e.g. forecasting) and **resources** (e.g. CAD). In opposition to importance factors, performance factors relate to **internal** variables.

Effects - Trade-offs affected this company's strategy and performance in 4 ways:

(1) Forcing the **setting of priorities** in strategy and performance - *"quality is our number one", "we don't trade-off quality"*. If there were no trade-offs, they could focus on each variable as independent and improve it indefinitely;

(2) Increasing the occurrence of **problems in related dimensions** - *'when products are faulty, their delivery is delayed'*. In a QD trade-off, quality faults might cause problems not only in quality but also in dependability;

(3) Limiting the **global competitiveness** - the development of 'World Class Manufacturing': *'Providing increasing variety*[5] *without being able to reduce the output rate is certainly a problem today'*;

(4) Limiting the rent of the system's **potential performance**: *"There is now the 'ability' to provide this variety but, as more and more products are asked at the same time, we still have a flexibility problem"* (M1). Differences between actual and potential performance might be explained at least in part by trade-offs.

Management - People suggested, as explained, that trade-offs were contingent and dynamic and thus could be managed. Here, managing trade-offs is to **improve their performance** and/or **minimise their importance.**

This company attempted to improve trade-offs along three major ways. First, by **focusing on the 'global' operations system.** This is to evaluate new improvements with their impact in multiple MSDs. For example, the performance of assembly teams was rated by a mix of performance measures relating to various dimensions.

Second, managers believed they could improve trade-offs by **focusing on the system's** set-up: *"I am convinced you can get an improvement in quality and dependability if you have your system set up right at the first time... to make sure*

[5] From now on, there will be no references to trade-offs involving flexibility (as a MSD) but involving variety instead. Case data suggest flexibility has the role of a process attribute only and should not be compared with other MSDs. The role of flexibility as a process attribute (to improve trade-offs) will be further discussed in following sections. The role of flexibility and variety in trade-offs will be further discussed in following chapters.

everything is right, and do not let it go until it is right" (M2). With trade-offs involving quality, they attempted to *'correct quality problems in their source'* and to *'get parts to come right at the first time'*, since *'intensifying quality inspections'* to improve quality had in the past damaged dimensions such as speed and dependability.

However, people assumed there was a **limit to the impact of improving capabilities** on trade-offs. M2, on improving supply management to improve CQ, suggested that *"... (there is one point when) we have to stop because we will not sacrifice quality."* Still, they did not know alternatives to improve trade-offs beyond such point.

As said above, another way to deal with trade-offs was to set competitive **priorities**. As M1 and M2 said, *"quality is our number one"* and *"we don't trade-off quality"*.

Finally, it is interesting how M2 justified the low importance of the CV trade-off: *'Increasing variety has a premium price that compensates increasing cost'*. He suggested its importance was lessened if there was a secondary benefit to **compensate** for the bad impact of one dimension on another. Increasing variety increased cost but was paid off by increasing *premium* prices.

7.1.3 Major Manufacturing Trade-offs

This section focuses on the most important trade-offs in Case A. The importance of trade-offs is a measure of their impact on MS. This is a report of these trade-offs on the following aspects: (1) trade-off description, justification and/or example in the case's context; (2) management approaches to deal with it; (3) resources, capabilities and/or process attributes relating to its management.

Quality and Cost, Case A: (1) For M2, this was an 'extremely important trade-off'. People knew ways of coping with QC, but, for M2, there was one point when "*... we have to stop because we will not sacrifice quality. The customer doesn't care what is our cost, they care for the quality only.*" (2) They suggested two solutions for QC.

One was to identify measures to reduce cost with no effect on quality (**priorities choice**). Another was to rate teams performance with a combination of objectives (**focus on system**) instead of single measures such as scrap rates or productivity. Nevertheless, quality remained a **priority** and managers felt they needed often to sacrifice cost to improve quality. (3) QC was positively affected by improving **capabilities** (due to training) and **attributes** - (a) *co-ordination* between design and manufacturing (design teams) and (b) product, programming and labour *flexibility*.

Quality and Dependability, Case A: (1) For M2, the QD trade-off occurred when one had to delay deliveries to assure that quality was acceptable. One example was returning faulty supply parts, thus delaying production schedules. For M1, quality had increased in recently years, but dependability had decreased due to problems with supply, inventory management and forecasting. (2) As with QC, this was managed by setting quality as **priority** and subordinating dependability to it. M2 justified saying that quality problems are perceived in the long-run while dependability problems are perceived (only) in the short-run. Later, he suggested that the right way to improve dependability without affecting quality was "*... getting the parts to come here right at the first time.*", which is system's **improvement**. (3) QD had been positively affected by improving **capabilities** (workforce *training* and *supply management*), **resources** (the *CAD* system) and **attributes** - *co-ordination* between design and manufacturing (design teams) and process and labour *flexibility*. The role of design teams, CAD, labour flexibility, training and supply management was 'making sure things are done right at the first time', minimising delays due to quality faults. This is to improve the system's *reliability*. The role of process flexibility was to improve the ability to cope with defective supply parts without affecting the dependability.

Quality and Speed, Case A: (1) QS was the most important trade-off there since (a) both quality and speed were very **important for competitiveness** and (b) management and operators assumed that, as M1 suggested, "*In general, the in-house quality measure 'defects per machine' increases with the build rate.*" As he pointed out, "*This is perceived both in shop floor and management and we accept that this is the reality for the time being and will be until our process improves and our capacity* *increases."* They always had problems with quality performance in supply and manufacturing but these only started to make real difference as the build rate increased with increasing sales. (2) For M1, improving QS demanded correcting problems in their source (**focus on system, improving** the system's reliability instead of focusing on quality output measures): *"What we try to do is we take the problem behind, back to their source, and attempt to correct the problem there."* (3) *"QS is still a trade-off, but I would say it has improved"* (M1). QS was positively affected by improving production **resources** - *workforce skills* due to training and a new *layout* based on assembly cells - and **attributes** - process, mix, labour, product and process *flexibility*. *"Now we are more readily adaptable to problems such as supply quality or supply delivery... the cell assemblies allow us to be more adaptable in overcoming these problems"* (M1). On the other hand, poor **capabilities** - *forecasting* and *supply management* - worsened the impact of QS as they made it more difficult dealing with production schedules (affecting speed) and the supply parts quality.

Speed and Dependability, Case A[6]: (1) M2 saw speed and dependability as intrinsically related: *"If we say that we will deliver in 40 days, than our dependability is 100%, but if we promise to deliver in 5 days, than our dependability won't be quite so high."* If increasing delivery speeds increased dependability problems, increasing dependability *goals* also harmed speed. (2) The solution thus relied on **improving** the ability to deliver fast and on time instead of focusing on the performance measures themselves. For M2, however, the solution was on setting dependability a **priority** over speed: *"I don't think that we will sacrifice our dependability for speed."*

7.1.4 Manufacturing Flexibility and Trade-offs

As has been discussed, flexibility is here considered a system's attribute instead of objective. Variety is the variable in trade-offs. The next chapter discusses this further.

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[6] This trade-off was included here *a posteriori* - it was not among any case's most important ones. The data on CD concerns only its description, with no references to its management. This is the same for CD in case C. These trade-offs were included to provide a formal analysis of all 10 trade-offs types defined in the research framework.

This section analyses the role of flexibility in the *management* of trade-offs. As pointed out in the last section, trade-offs could and usually were affected positively by increasing resources, capabilities and attributes such as flexibility. The case data suggested that, by improving specific flexibility types by increasing resources and capabilities, one might improve the performance of trade-offs. To improve a trade-off performance is to reduce its strength, that is the correlation between its variables.

The following analysis thus examines the evidence from Case A (and from the other cases in following sections) relating to this idea. This analysis concerns four aspects: (1) which flexibility types related to the improvement of which trade-offs; (2) how this relationship occurred; (3) which resources and capabilities related primarily to the development of these flexibility types and (4) how this development occurred. This analysis is in Table 7-3. Figure 7-2 illustrates the network of relationships suggested in Case A. Following sections present similar analyses for the other cases.

Flexibility Type	Related Capabilities/ Resources	Nature of Impact Cap./Res. → Flexibility Type	Related Trade-offs	Nature of Impact Flexibility Type → Trade-off
Process (7)	Assembly cells, Operation abilities	Assembly cells improve ability to work with different materials and in different sequences.	QS QD SV	Process flexibility improves ability to reallocate jobs, minimising speed problems caused by quality failures (QS); Increases ability to work with varying/faulty materials reducing dependability problems (QD); Improves ability to offer variety at increasing speed (SV)
Mix (2)	PPC, Assembly cells, MRP II	Assembly cells and MRP II provide ability to manage variety and complexity in PPC and shop-floor.	QS	Mix flexibility increases the ability to guarantee quality at increasing speed (QS).
Labour (11)	Labour skills, Training, Assembly cells	Training and cells improve the range and performance of operators' skills increasing their flexibility.	QS QD QC SV	Labour flexibility increases the ability to guarantee quality at increasing speed (QS); Increases autonomy and skills of workers, enabling working with better quality and dependability (QD); Labour flexibility increases workers autonomy making it possible working with better quality and cost (QC); Labour flexibility improves ability to offer large variety at increasing speed rates (SV).
Product (1)	Product Design, CAD, Design for manuf'bility	CAD and design for manufacturability reduced time of product introduction by 50%	QS SV QC	Product flexibility increases the ability to guarantee quality at increasing speed (QS); Improves ability to offer variety at increasing speed (SV) Increases products manufacturability making it possible working with better quality & cost (QC).
Programming (8)	Labour skills, Training	Training increases range of operators' skills increasing their autonomy.	QC QD	Programming flexibility increases autonomy making it possible working with better quality and cost (QC); Increases autonomy making it possible working with better quality and dependability (QD).

Table 7-3: The impact of flexibility types on trade-offs: Case A

Table 7-3 is as following. (a) The first column lists the flexibility types that seemed to have the biggest effect on trade-offs in the case. (b) The two following columns present the capabilities and/or resources relating to the performance of those types and discuss how this occurred in the case. (c) The final columns present the trade-offs that were affected by each increasing flexibility type and the nature of this impact. Figure 7-2 illustrates these relationships. Trade-offs are at the top, flexibility types (Fn) at the middle and resources (Rn) and capabilities (Cn) types at the bottom of the figure.

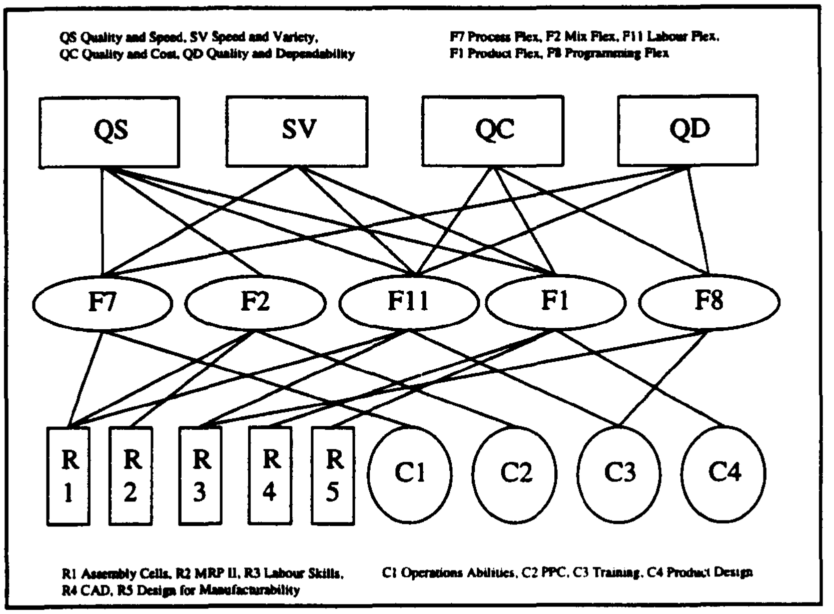

Figure 7-2: Network of flexibility types, trade-offs, resources and capabilities: Case A

7.1.5 Data Summary - Case A

Table 7-4 presents a data summary for case A.

Section	Subject	Characteristics
Company's Background	Description	Mechanical equipment manufacturer in Midlands, UK; 1100 employees; 200 million pounds revenues.
	Shop-Floor	Assembly plant (3 lines); 550 operative workers.
Manufacturing Trade-offs	General View	Trade-offs as compromises; relevant.
	Nature	Dynamic; limit for improvement; contingent.
	Importance Factors	3; external; market and strategy variables.
	Performance Factors	15; internal; attributes, resources and capabilities.
	Effects	Priorities choice; problems to related dimensions; limit global performance; limit rent of potential performance.
	Management	Improvement; focus on system; priorities setting; compensation.
Major Trade-offs	Major Trade-offs	QC, QD, QS, SD.
	Ranking of MSDs: Importance	Q, S & D, V, C.
Manufacturing Flexibility and Trade-offs	Major Flexibility Types	Process, mix, labour, product, programming.
	Related Trade-offs	QS, QC, QD, SV.
	Related Capabilities	Operations abilities, PPC, training, design.
	Related Resources	Assembly cells, MRP II, Labour skills, CAD, design for manufacturability.

Table 7-4: Data summary: Case A

7.2 Case B - The British Plastics Packaging Manufacturer

7.2.1 Company's Background

<u>**Strategy**</u> - Case B was a plastic packaging manufacturer from North Wales. This was a subsidiary of a firm operating in the USA, UK and Australia as a manufacturer of coated films, paper and packaging. The firm was founded in the early 1900's in the USA as a paper manufacturer and has since expanded world-wide. It employed around 20,000 people world-wide (50% are in the UK). This plant employed 170 people, 120 in the shop-floor and 50 in the office.

The site was a process plant manufacturing coating films (4 types) for electronics and civil engineering industries. The main type corresponded to 65% of the turnover.

The site operated in a make-to-order basis. About 15 major clients corresponded to 90% of the turnover. Customers were in close contact with the company and made regular orders. The company's mission was to provide products within 'required' quality standards, at acceptable cost and delivery speed. Meeting customer's specifications was the main priority in OM.

The company was in close contact with 25 major suppliers (corresponding to about 75% of its purchasing value). About 50% of supplies were from the UK, 25% from Europe and 25% from the USA. The turnover in 1995 was around 20 million sterling pounds and increasing. About 60% of sales were for the UK and 40% for Europe.

The site had four management levels. There were six more top levels in the UK and world-wide. The strategy for this site included all the firm's UK operations. It comprised a period of 5 years and was revised annually.

<u>**Shop-Floor**</u> - The shop-floor had a process layout divided into four main stages. The stages were semi-integrated. Work-in-progress moved from on stage to another either manually or automatically.

The 1994's set-up of team-working and cells was the major change in shop-floor organisation in recent years. Cells did not mean here the arrangement of machines - the site remains a typical process system - but rather the training of multi-skilled team-workers to perform activities once allocated to peripheral areas such as design, quality control and maintenance. The introduction of cells and team-working went with other personnel policies such as lower supervision and a revised benefits system.

The company qualified in 1992 for the ISO 9001 and in 1993 a new management changed the performance control systems on shop-floor. Management started in 1996 to implement a MRP system, following the allocation of PPC to the cells level.

Three people were interviewed in this case: the Production Manager (M1), the Quality Manager (M2), and the Cells Manager (M3). The data collection was in July 1996.

7.2.2 Manufacturing Trade-offs

General View - Managers followed the classical **view** of trade-offs as compromises between competitive dimensions or objectives. The ideas proposed were easy to **understand** as people could link trade-offs ideas with their reality.

Trade-offs in this case were in two extremes. Most trade-offs suggested were not considered existent by most or all the managers interviewed. In this category were QD, CS, CD, SD, SV and DV. On the other hand, QC, QS, QV and CV were **considered** by most managers and scored high degrees of **importance**. These were **relevant** to the company's competitiveness. Specially QC, QS and QV were in the core of recent decisions with effect in their strategy and performance.

The reason managers seemed to have different views on whether specific trade-offs existed and with which importance seems to concern their different **approaches**. Managers tended to assess trade-offs following personal conceptions and roles. For instance, M2 (the quality manager) saw QC as existent and important, while M3 (the cells manager) thought QC did not exist. The case is, for M2, quality meant *performance* and *conformance* (and quality performance was more than simply 'rate of scrap and reworks'), while M3 saw quality only as *performance* (which is compatible with cost productivity and thus eliminates this trade-off).

Finally, managers might consider some trade-offs '**people's perception**' only. As M1 pointed out, "*You actually find that, as soon as you say 'speed' to people, the actual reaction is that quality will go down; this is a human element, they don't want to increase speed, they think things will be hard to follow.*" This is not to say that managers' views could not follow the same sorts of perception as 'other people's'. It only suggests that the way they dealt with trade-offs could depend on whether they saw trade-offs as existing or only as perception of 'people in the shop-floor'.

<u>Nature</u> - People acknowledged that trade-offs are **dynamic** and can be **improved**. However, they had different views on how to deal with trade-offs. Only M1 was able to exemplify an approach to trade-offs improvement as anticipated in this research: "*By putting a CIM system enabled us to track our quality (on-time) and it made the trade-off between quality and speed weaker.*" M2 agreed that developing resources and capabilities might affect trade-offs but could point out only negative effects (specially concerning cells and team working on QC). M3 had a mixed view. She believed that trade-offs could be improved 'in the long-term'. In the short term they would require 'static' measures such as setting priorities in performance.

M1 and M2 had interesting views regarding the **contingency** of trade-offs. They suggested why some trade-offs seemed not to apply in this case. First, they suggested that trade-offs such as CS did not exist because this is a process company, where one can improve both variables by similar measures. M2 also believed that other trade-offs did not exist because (2) the system was operating well below its potential performance and (3) the company had been able to deliver as required by customers. "*Maybe if the pressure keeps on and we have to keep on increasing the speed then at* *some part presumably there will be a trade-off.*" The gaps between actual and potential performance might explain why some trade-offs existed or not.

Finally, some trade-offs (such as QC, QS and QV in M2's view) were treated as if they had **related** origins or effects. Improving such trade-offs could also ground on similar measures.

<u>**Importance Factors**</u> - Table 7-5 presents the major factors relating to the importance of trade-offs in Case B.

Importance Factor	Trade-offs Affected
Level of customer requirements	General trade-offs Speed and Variety)
Strength of market competition	General trade-offs

Table 7-5: Trade-offs importance factors in Case B

The level of customer requirements and the strength of market competition seemed to determine in this case the impact of trade-offs on the strategy. These were Case B's **two importance factors.** They related to the **external environment** and concerned **market variables.**

<u>**Performance Factors**</u> - Table 7-6 summarises the major variables that determined the performance of trade-offs in Case B.

Performance Factor	Trade-offs Affected
Machine flexibility	Quality and Speed, Speed and Variety, Cost and Variety
Process flexibility	Quality and Speed, Speed and Variety, Quality and Cost
Delivery flexibility	Cost and Variety
Production flexibility	Cost and Variety
Set-ups	Speed and Variety, Cost and Variety
Workforce training	Quality and Speed, Speed and Variety
Production abilities	Quality and Variety
Scheduling	Cost and Variety
Process quality control	Quality and Speed
Process technologies	Quality and Cost
Workforce skills	Quality and Cost
SPC methods	Quality and Speed
Process instrumentation	Quality and Speed
CIM system (sensors)	Quality and Speed, Speed and Variety

Table 7-6: Trade-offs performance factors in Case B

These performance factors are in three categories: (1) process attributes, (2) activities (capabilities), and (3) resources. Case B thus had **14 performance factors**, relating to **process attributes, capabilities and resources** and concerning **internal variables**.

Effects - People suggested that trade-offs might affect this system in two ways:

(1) Forcing the setting of **competitive priorities**[7], since it is not possible to be competitive in all areas. M1 illustrated this point: *"My approach is what I have as my 'priorities of life'... I put health and safety number one and then I put quality, yield, then I put speed... and the rationale behind this is that people should come before everything else and quality comes after because if you don't have quality it will cost you far more once you get it back from the customer... yield then because I think yield is more important than speed."*

(2) Limiting the rent of the system's **potential performance**. According to M2 and M3, the actual production speed had been kept below the potential to minimise costs with waste and rework.

Management - As discussed above, managers agreed that developing resources and capabilities could change the nature of trade-offs. However, they disagreed on the extent of their effect as alone. M1 provided examples of fully **improving** trade-offs such as QS and SV by **resources** such as electronic sensors and **capabilities** such as set-ups. M3 agreed but suggested that a mix of **static** and **dynamic** measures could be also necessary: *"I think people need to be realist about what they want to achieve... and keep on questioning why this is a problem, and solve this."* The first part of her statement suggests a static measure such as setting priorities or finding an equilibrium in performance while the second part is in line with M1's idea.

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[7] Effects relate essentially to reactive measures for trade-offs management. Effects *force* management to deal with trade-offs in such ways.

Still on this point, M2 suggested that the correct approach to improve trade-offs was **focusing on the system** rather than on (isolated) variables: *"I think that really the key to all this is that everybody has to focus on the common good."* His best examples were on trade-offs with quality. He said their worsening in performance was due to measures such as reducing workforce to save costs: *"Recently we had to cut people... as the result of the downsizing some jobs disappeared and quality control worsened... Maybe with time we are going to recover from that."* He attributed the decrease in QC's performance to worse quality control activities. He suggested how the company might recover from that: *"You can't improve quality by increasing the level of inspections, that will obviously increase the cost... one way we have to improve quality is to make people more responsible for their own activities... you can achieve improvements in quality there with no increasing cost."*

Finally, managers suggested other ways of dealing with trade-offs than improvements. M1 suggested setting **priorities** in performance: *"My approach is what I have as my 'priorities of life'..."* (see this transcription above). M2 believed people should find an **equilibrium** in performance goals that might satisfy everybody: *"There can be conflicts there because with the greater emphasis in terms of costs or perhaps on reducing waste, the production cells may say 'I don't want to increase my speed because that will increase the waste and that is contrary to my objectives', so they can be conflicting objectives... The solution is by negotiation and resolving conflicts."* M3 suggested that the first step on coping with trade-offs such as QS and SC was to **reduce the competitive importance** of speed. This would allow reducing its performance and thus minimising costs with waste.

7.2.3 Major Manufacturing Trade-offs

The most important trade-offs in Case B were CV, QC, QS and QV. Among these, QC, QS and QV appeared about the same time, after the introduction of cell teams and the reduction of the labour contingent in the shop-floor. For M2, with the cells, *"It* *became, first of all, much more difficult to even measure the costs of quality.*" These trade-offs were related in this sense, although they had different bases.

Cost and Variety, Case B: (1) For M3, the major problem with increasing variety was losing scale economies. Increasing variety would require working with smaller batches, more frequent set-ups and more work-in-process. These factors would increase costs such as with set-ups, waste and inventories and decrease the fixed cost productivity. (2) The solution to CV was to **improve** the system's ability to work economically with smaller batches. (3) This is to improve *scheduling* and *set-ups* **capabilities**, leading to scope economies that compensate for losing scale economies. For M3, delivery, production and machine *flexibility* were the fundamental **attributes** to cope with CV.

Quality and Cost, Case B: (1) There were different approaches to this trade-off. M2 thought that increasing cost productivity would damage quality (e.g. in labour downsizing). M3 pointed out that improving quality should save costs with waste. It seems that, out of the two types of quality costs (prevention and waste), waste was the most important in this plant. The cost of quality prevention was 'fixed' in the process technology and seemed not to vary largely with increasing quality. (2) In this context, focusing on reducing waste through improvements in quality control seemed the best approach here. This required **improving** the *quality assurance* rather than the *quality inspections*. As M2 pointed out, "*You can't improve quality by increasing the level of inspections, that will obviously increase the cost... one way we have to improve quality is to make people more responsible for their own activities... you can achieve improvements in quality there with no increasing cost...*" (3) Improving QC thus relied on better *process technology* (**resource**), *workforce abilities and responsibilities* (**capabilities**) and *process reliability* (**attribute**).

Quality and Speed, Case B: (1) The problem with QS was that increasing speed was making it more difficult to inspect quality. This was suggested by M1 and M2: "*I think our drive is to run as fast as possible, and sometimes if you run quickly you can miss things and you can not inspect things in the way you would like*" and "*If you* *increase speed it gets far more difficult to the groups to see the defects because a lot of quality issues are on inspection.*" Besides, increasing speed increased waste, since more material would be processed out between the problem occurrence and its detection. This trade-off was well acknowledged there: "*You actually find that, as soon as you say 'speed' to people, the actual reaction is that quality will go down; this is a human element, they don't want to increase speed, they think things will be hard to follow*" (M1). (2) M2 and M3 proposed a variety of solutions to this trade-off. For M2, QS required finding and **equilibrium** between the two objectives: "*The solution is by negotiation and resolving conflicts.*" M3 suggested that it might be necessary to **reduce** the speed in the short-term; long-term solutions depended on **improving** the process. (3) Such improvement relies on developing *quality control* **capabilities** in combination with **resources** such as *sensors* and *statistical process control (SPC) methods*. For M1, QS relied also on better machine and process *flexibility* (**attributes**), better *instrumentation* (**resources**) and *training* (**capabilities**).

Quality and Variety, Case B: In M2's view, the introduction of multi-skilled jobs and team-working de-focused people off specific functions, including quality control. "*If you try to do many things maybe you don't do anything as perhaps you ought to.*" In his view, increasing jobs variety decreased quality performance. (2) He thought the solution relied on assigning responsibilities, re-focusing people on specific tasks and reducing jobs variety: "*You need to have somebody to be responsible by quality altogether... it is not a training issue, at some part the responsibility has to come to a focus.*" (3) This might be translated into (re)defining focused process **capabilities** as the responsibility of named agents.

7.2.4 Manufacturing Flexibility and Trade-offs

Table 7-7 summarises the relationships between flexibility and trade-offs in Case B.

Flexibility Type	Related Capabilities/ Resources	Nature of Impact Cap./Res. → Flexibility Type	Related Trade-offs	Nature of Impact Flexibility Type → Trade-off
Machine (10)	Set-ups, manuf. cells	Cells put more emphasis on co-ordination and set-up times reduction, increasing machine and production flexibility.	QS SV CV	Machine flexibility improves the ability to work with increasing speed and variety with no harm to quality (QS, SV); Machine flexibility improves the ability to work economically with increasing variety (CV).
Process (7)	Supply mgt., new materials	Better supply mgt. and new materials increase the range and quality of raw materials available.	QS SV	Process flexibility improves the ability to work with increasing variety and quality with no harm to speed.
Delivery (3)	Scheduling, cells, perf. measurement	PPC has been moved into cells improving the accuracy and range of sequences to be planned. Better performance measurement helps to evaluate such improvements.	CV	Delivery flexibility improves the ability to work economically with increasing variety (CV).
Production (4)	Set-ups, cells, performance measurement	Cells put more emphasis on co-ordination and set-up times reduction, increasing machine and production flexibility. Better performance measurement helps to evaluate such improvements.	CV	Production flexibility improves the ability to work economically with increasing variety (CV).

Table 7-7: The impact of flexibility types on trade-offs: Case B

Figure 7-3 summarises the network of relationships suggested in Case B.

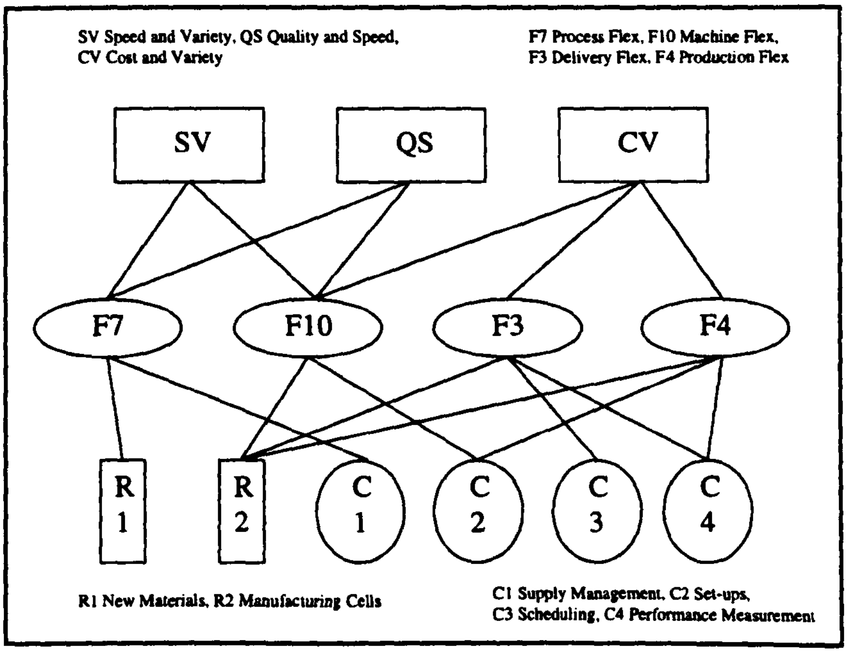

Figure 7-3: Network of flexibility types, trade-offs, resources and capabilities: Case B

7.2.5 Data Summary - Case B

Table 7-8 presents a data summary for case A.

Section	Subject	Characteristics
Company's Background	Description	Plastics packaging manufacturer in North Wales, UK; 170 employees; 20 million sterling pounds revenues.
	Shop-Floor	Process plant; 120 operative workers.
Manufacturing Trade-offs	General View	Trade-offs as compromises; relevant; also human perception.
	Nature	Dynamic; contingent; related.
	Importance Factors	2; external; market variables.
	Performance Factors	14; internal; attributes, resources and capabilities.
	Effects	Priorities choice; limit rent of potential performance.
	Management	Improvement; focus on system; importance reduction; priorities setting; finding equilibrium.
Major Trade-offs	Major Trade-offs	CV, QC, QS, QV.
	Ranking of MSDs: Importance	Q, S, C, V, D.
Manufacturing Flexibility and Trade-offs	Major Flexibility Types	Process, machine, delivery, production.
	Related Trade-offs	SV, QS, CV.
	Related Capabilities	Supply management, set-ups, scheduling, performance measurement.
	Related Resources	New materials, manufacturing cells.

Table 7-8: Data Summary: Case B

7.3 Case C - The Brazilian Shoes Manufacturer

7.3.1 Company's Background

<u>Strategy</u> - Company C was a shoes manufacturer from South Brazil. The company had one plant in South Brazil and another in the country's Northeast. It was founded in 1971. It employed about 8.000 people (3.500 in the South - 80% in shop-floor - and 4.500 in the Northeast). Case C is about the Southern unit.

Initially, the company's mission was to manufacture plastic nets (jackets) to wrap 5-litre wine bottles, making then safer to handle and store. The Southern unit was set up in a traditional wine-making area in South Brazil. The company was thus designed to deliver a single product to a well-defined market.

From around 1978, however, the company's founder decided to leave the command to his two sons. This transition was beneficial to the company. The new managers realised that the old wineries market was getting too unstable and they should look for new markets and products. They thus started making shoes. However, since the company was a plastics manufacturer and had no previous experience with other materials or processes, they decided to make plastic shoes... in fact, plastic sandals for girls aged 6-12. Grounded in an extensive marketing campaign, they turned this innovative product into a market success.

As the strategy worked out, the company diversified to other markets and products. Today, it bases its strategy on two major lines: mules and sandals (about 60% of sales) and tennis shoes (40%). This plant had three focused factories delivering shoes to about 3,000 distributors world-wide. Products were made-to-order and made-to-stock, depending on clients requirements, product type and the season. The strategy followed three major aims that were (1) gaining market share; (2) delivering fashionable, diversified products and (3) being a low cost producer. The company had more than 120 products in line (with varying design, colours and materials), renewed twice a year. This means more than 200 new products being designed or modified each year.

<u>Shop-Floor</u> - This site had three factories. Factory 1 made tennis shoes, factory 2 made mules and sandals and factory 3 made the best-seller mules. The site employed 2,800 people in the shop-floor.

The factories were divided mostly into functional areas. Some manufacturing cells had been introduced with success. Each factory had 4 major sections: fabrication, sewing, assembly and packaging. Most operators worked in the sewing area and management had no intention to automate this section.

The newest technologies were in the assembly area. There, big automated assemblers put together all the components made in the other sections. These machines were specially important in the tennis shoes factory.

The major technologies and methodologies implemented in these factories in the last years were (in design) CAD, CAM and simultaneous engineering and (in manufacturing) numerically controlled machines, set-up times reduction, quality groups and work teams. The impact of these improvements was positive. People suggested their major benefits concerned innovativennes, agility, quality and low cost.

Three people were interviewed in this company: the PPC manager for factory 1 (M1), the PPC manager for factories 2 and 3 (M2) and the IT manager (M3). The interviews and visits to shop-floor were in May and June 1996.

7.3.2 Manufacturing Trade-offs

General View - In Case C, different people had different **views on trade-offs**. M1 viewed trade-offs as compromises between objectives. M2 saw trade-offs as 'interdepartmental conflicts'. He attributed the responsibility for specific dimensions to different areas (somehow as cost for design, dependability for sales, speed and quality for manufacturing, variety for PPC). M3 had few ideas about trade-offs and needed some good explanation on the subject.

For M2, trade-offs are **relevant** for two reasons. First, he viewed MSDs (in spite of those 'interdepartmental conflicts') as intrinsically **related**. Second, the firm needed to accomplish winning performances in many of such variables. As he suggested, "... *the problem is global and can not be divided in compartments like this.*"

Managers considered most trade-offs suggested as **existent** and with different degrees of **importance.** M1 believed that all trade-offs existed in this company. M2 could see all but QC, CS and SD that he considered mutually enhancing. M3 could see all trade-offs but CS. He considered all those trade-offs 'fairly important'.

It is interesting noting that managers seemed to have different approaches for describing trade-offs. M2 said that there was no trade-off between QC because "*The more quality you have, the lower is the cost... if 10% of a batch are scraped, my cost increases a lot.*" This was not entirely correct, since in this company (as in most other companies) the costs with quality prevention and control were also important. He did not see these trade-offs because he did not consider all the variables involved. It was also interesting that M3 only saw the other side of the problem: "*I feel that, increasing* *quality, costs also increase... this is a very important problem."* This example shows how different (and partial) approaches to trade-offs may lead to different perceptions on their existence and importance.

Nature - M1 and M2 believed that trade-offs were **dynamic** and could be **improved**. *"Since we created the work teams, these things improved. Every week we summarise the problems occurred and arrange a meeting to discuss these problems and try to solve then... (trade-offs) improve when we solve those problems"* (M2). M3 did not think that trade-offs could be improved. Instead, he suggested that one should compensate trade-offs by benefits generated in other areas. Examples of such benefits are *premium* prices or increasing market share.

Managers suggested that the importance and performance of trade-offs were **contingent** to environment variables. They related these to a range of internal and external factors (following discussed). For example, M1 believed that the performance of QC as relating to new products was different from QC as relating to traditional products. M2 believed that the performance of QS depended on the level of operators' skills. Some trade-offs might also be **related,** i.e. have similar sources or effects. M1 thought that CS, CD and CV were all due to the impact of speed, dependability and variety on cost. M2 suggested that CV and SV were a similar sort of problem.

Importance Factors - Table 7-9 summarises the major variables that determined the importance of trade-offs in Case C.

Importance Factor	Trade-offs Affected
Range of market segments	Quality and Variety
Strength of competition	All
Products life cycle	Quality and Cost
Customer expectations	Quality and Speed

Table 7-9: Trade-offs importance factors in Case C

This company makes a large variety of products for different market segments. This makes QV specially important: *"This is very important... we have 124 models and we know that it makes it difficult to guarantee their quality"* (M1). The second factor, the strength of market competition, was probably important for all trade-offs: *"Because the market is ever more competitive, we need to be good on all these five objectives simultaneously..."* (M1). The length of products life cycle determined the importance of QC. Guaranteeing the quality of new products seemed more expensive than that of traditional products. Customer expectations related mostly to QS.

Thus, Case C suggested **four importance factors**. They all related to the **external environment** and concerned **market and strategy variables.**

The importance of trade-offs depended not only on the impact of those factors on MSDs 'as related'. The importance of 'individual' trade-offs variables was also a major determinant of the importance of the trade-offs that they made part. For example, SD and DV had little importance simply because dependability was not important as a competitive objective.

Performance Factors - Table 7-10 summarises the major variables that determined the performance of trade-offs in Case C.

Performance Factor	Trade-offs Affected
Machine flexibility	Cost and Variety; Dependability and Variety; Dependability and Speed
Volume flexibility	Cost and Variety; Dependability and Variety; Dependability and Speed
Labour flexibility	Dependability and Variety; Dependability and Speed; Quality and Variety
Delivery flexibility	Dependability and Variety; Dependability and Speed
Product flexibility	Quality and Variety
Process flexibility	Quality and Cost; Quality and Variety
Process reliability	Quality and Cost
System's co-ordination	All
Inventory management	Cost and Variety
Logistics management	Variety and Dependability
Machine and line set-ups	Cost and Variety; Speed and Variety; Dependability and Variety; Dependability and Speed
Forecasting	Quality and Variety
Workforce training	Dependability and Variety; Dependability and Speed
Product development	Quality and Variety
Supply management	Quality and Cost
New technologies and methodologies (NC machines, process technology, cells)	Cost and Variety; Speed and Variety; Quality and Cost; Quality and Variety; Variety and Dependability; Dependability and Variety; Dependability and Speed
Workforce skills	Speed and Variety; Quality and Cost; Quality and Speed; Quality and Dependability

Table 7-10: Trade-offs performance factors in Case C

The performance factors in Table 7-10 may be divided into three categories. The first concerns process attributes (flexibility, reliability and co-ordination). The second refers to process capabilities such as inventory and supply management, forecasting and product development. The third refers to resources such as process technology and workforce skills. Case C thus suggested **19 performance factors** concerning **process attributes, capabilities and resources** and referring to **internal variables.**

Effects - Trade-offs seemed to affect this company in two major ways:

(1) Limiting the renting of the system's **potential performance** - For example, the existence of a DV trade-off implied that OM had to limit the number of changes in set-ups and production schedules. The system was 'technically' able to cope with such changes but they had usually a bad impact on dependability;

(2) Creating problems to **related dimensions** - It was often difficult to cope with the impact of increasing speed, dependability or variety on cost.

Management - M1 and M2 suggested that OM could **improve** trade-offs through improving the system's **resources and capabilities**. In M1 words: *"Because the market is ever more competitive, we need to be good on all these five objectives simultaneously... for this we need better technologies, processes, products, workforce... we need to be agile, we need to always improve."*

M2 suggested that simply 'implementing' new technologies could not guarantee improvements in performance. They should be properly integrated with other resources and capabilities. For example, the impact of new process technologies on CV depended in great extent on their integration with inventory management and maintenance. M3 thought that one could not improve trade-offs but only **compensate** their effects with benefits in other areas. Concerning QC: *"I think that every time you aggregate something to the product, it requires new components or technologies and all this increases costs... You compensate these costs with increasing market share or higher prices."*

One could also view the performance of trade-offs as a function of the **system's attributes**. M1 pointed out the role of process reliability on improving QC and QV: "*We have been trying to improve the process reliability... to (be able to) work with advanced technologies, tools, materials and methods.*" **Flexibility capabilities** had also major importance in this context.

Another idea for improving trade-offs was **focusing on the system** (rather than on objectives). This concerns an integrative, team working approach on management. M2 illustrated the role of work teams in the analysis and improvement of trade-offs: *"Since we created the work teams, these things improved. Every week we summarise the problems occurred and arrange a meeting to discuss these problems and try to solve then... (trade-offs) improve when we solve those problems."* M3 suggested that the role of workgroups was to 'resolve conflicts' and find out 'fair' solutions to otherwise opposing objectives of different areas: *"To resolve these incompatibilities, the company created workgroups... products design is now a responsibility of a team including manufacturing, sales, information technology and design... so, the salesman has to agree with the operations manager on the products characteristics... so I think we don't have these conflicts anymore."*

Dealing with trade-offs may follow also other solutions (different from improvement). M2 suggested dealing with DV thought setting dependability as **priority** over variety: "*What we try to do here is to avoid changing the machines schedules and to minimise the number and duration of set-ups to be able to deliver on time...*"

7.3.3 Major Manufacturing Trade-offs

All the most important trade-offs in Case C involved variety - QV, CV, SV and DV. Variety was a major issue there. This company had more than 120 products in line renewed twice a year. That means more than 200 new products being designed or modified each year. These trade-offs are following discussed.

Cost and Variety, Case C: (1) This case with cost and variety compares with ideas in the literature (see Chapter 3). M1 and M2 suggested that increasing variety increased costs with set-ups, waste and inventories. (2) They dealt with CV by developing resources and capabilities that were able to work with large varieties at minimal cost. This is to **improve** areas such as process technology, flexibility and work skills. (3) The elements that enabled the company to deal with CV under this approach were *NC machines* and *manufacturing cells* (**resources**), *set-ups* and *inventory management* (**capabilities**) and *machine and volume flexibility* (**attributes**).

Dependability and Variety, Variety and Speed, Case C: (1) These trade-offs were related in this case. Increasing variety increased the number of set-ups and the complexity of the system. These harmed the speed and dependability performance. (2) The best way to deal with DV and SV was to **improve** the elements that could cope with increasing variety with a small effect on dependability and speed. This involved better process technology, labour skills and scheduling: "*Besides that, we have been trying to improve our deliveries system; we try to combine the various production orders according to their sales areas...*" (M2). Increasing variety did affect dependability. However, for M2, "*These losses would have been much worse in the old delivering system.*" (3) The elements best relating to this approach were *process technologies, NC machines* and *cells* (**resources**), *set-ups* and *training* (**capabilities**) and *machine, volume, labour and delivery flexibility* (**attributes**).

Quality and Variety, Case C: (1) "*This is very important... we have 124 models and we know that it makes it difficult to guarantee their quality*" (M1). Again, high variety increased the complexity of OM. (2) The constant introduction of new products (about 4 a week) required systematic training, defining new work methods and improving quality control procedures. Management focused also on **improving** the production supply, production planning and flexibility: "*Supply materials must be delivered with high quality and variety*" (M1). (3) This concerned better *forecasting* and *product development* (**capabilities**) and *process, labour and product flexibility* (**attributes**).

Cost and Dependability, Case C[8]: (1) Managers thought (first) that increasing cost productivity harmed dependability and (second) that increasing dependability increased cost. There was a cost with providing a structure to support dependability performance. This was defined by M2: "*There is a divergence here, yes... If I start changing operations schedules, the cost in that week will be high.*"

7.3.4 Manufacturing Flexibility and Trade-offs

Table 7-11 has the analysis of the relationship between flexibility and trade-offs in Case C.

Flexibility Type	Related Capabilities/ Resources	Nature of Impact Cap./Res. → Flexibility Type	Related Trade-offs	Nature of Impact Flexibility Type → Trade-off
Process (7)	Training, new technology	Better process technology and training improved the system's ability to cope with an increasing range of materials and activities (production sequences).	QC QV	Improved the relationship between cost and quality (QC). Improved the ability to work with increasing variety without damaging other dimensions (QV).
Labour (11)	Labour skills, training	Regular training improves workforce skills and flexibility.	QC QV SV	Improved the relationship between cost and quality (QC). Improved the ability to work with increasing variety without damaging other dimensions (QV, SV).
Product (1)	Design, CAD, CAM, forecasting, design teams, supply management	New product-focused design teams associated with CAD and CAM technologies improved design response and co-ordination with manufacturing. Forecasting and better supply management increased the quality of information for design teams.	QV	Improved design speed and manufacturability of new products making it easier coping with increasing performance requirements for both quality and variety.
Machine (10)	Set-up, NC machines	NC machines and set-up reduction methods reduced set-up times improving machines flex.	CV SV	Improved the ability to work with increasing variety without damaging other dimensions (CV, SV).
Volume (5)	Inventory management, MRP	MRP system improved inventory management and volume flexibility.	CV SV	Improved the ability to work with increasing variety without damaging other dimensions (CV, SV).

Table 7-11: The impact of flexibility types on trade-offs: Case C

Figure 7-4 summarises the network of relationships suggested in case C.

[8] This has been included by the same reason as SD in Case A.

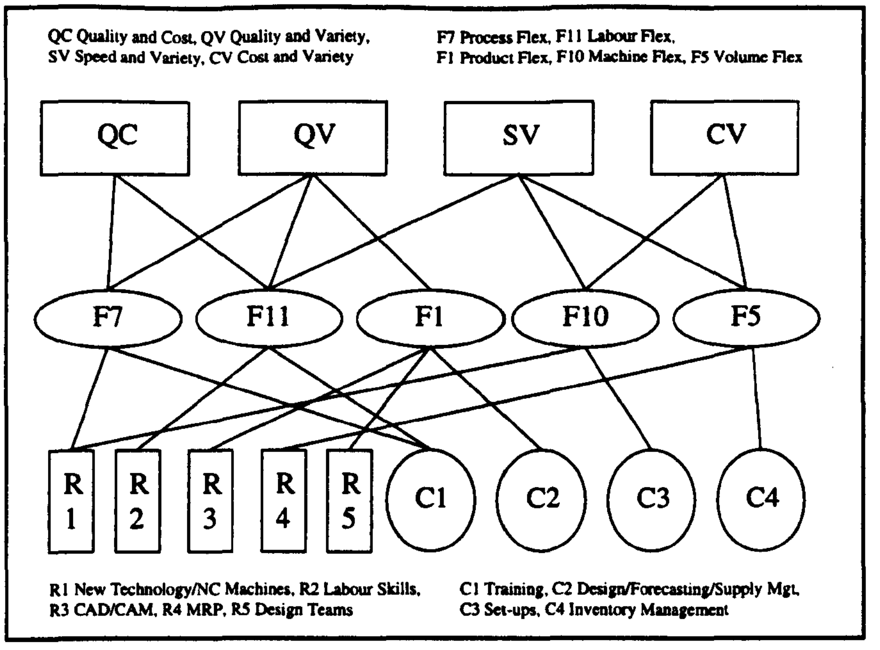

Figure 7-4: Network of flexibility types, trade-offs, resources and capabilities: Case C

7.3.5 Data Summary - Case C

Table 7-12 presents a data summary for case C.

Section	Subject	Characteristics
Company's Background	Description	Shoes Manufacturer in South Brazil; 3500 employees; 200 million sterling pounds revenues.
	Shop-Floor	Manufacturing and assembly plant; 2800 operative workers.
Manufacturing Trade-offs	General View	Trade-offs as compromises and as conflicts between areas; relevant; varying importance.
	Nature	Dynamic/static; contingent; some are related.
	Importance Factors	4; external; market and strategy variables.
	Performance Factors	19; internal; attributes, resources and capabilities.
	Effects	Problems to related dimensions; limit rent of potential performance.
	Management	Improvement; priorities setting; compensation.
Major Trade-offs	Major Trade-offs	QV, CD, CV, SV, DV.
	Ranking of MSDs: Importance	V, Q, D, C, S.
Manufacturing Flexibility and Trade-offs	Major Flexibility Types	Process, labour, product, machine, volume.
	Related Trade-offs	QC, QV, SV, CV.
	Related Capabilities	Training, design, forecasting, supply management, set-ups, inventory management.
	Related Resources	New technologies, NC machines, labour skills, CAD, CAM, MRP, design teams.

Table 7-12: Data Summary: Case C

7.4 Case D - The Brazilian Automotive Components Manufacturer

7.4.1 Company's Background

<u>**Strategy**</u> - Company D was in South Brazil. It was part of a multinational group manufacturing automotive components. The group had 3 units in Brazil. This company was formed as a joint-venture between the two major world competitors in this market. This unit had the responsibility to develop and manufacture high-technology, reliable parts to car factories in Brazil and abroad. Its major clients were Volkswagen, General Motors, Fiat and Ford.

This unit employed 700 people in the shop-floor and 600 in design and management. It was set up in 1974. Its turnover was around 110 million sterling pounds a year.

The factory worked in both make-to-order and make-to-stock bases. Products were developed either in-house or in the clients laboratories, depending on their R&D policies. There was a straight co-operation between company and customers in the specification, design and test of new parts. On the other hand, suppliers of this factory had almost no participation in this process.

<u>**Shop-Floor**</u> - There were different types of layout in this plant. Fabrication areas were organised within manufacturing cells and functional departments. Assembly areas were organised within traditional assembly lines.

OM provided great emphasis to process control, communication and safety in the shop-floor. There were control charts and graphs displayed about everywhere. The company had implemented many advanced manufacturing technologies and methodologies. These include Total Quality Control (leading to the qualification for ISO 9000 in 1991), Theory of Constraints (concerning activities such as production planning and set-ups) and Total Preventive Maintenance. Design had an integrated CAD/CAM/CAPP system in full operation.

Manufacturing areas had technologies such as NC machines, automatic loaders and automated transport systems. It is their policy to test most of the new technologies and methodologies available. People considered this policy highly successful.

The most recent 'major' idea there was the application of Theory of Constraints principles. Production planning is now bounded by 'bottleneck' and 'critical resources constraints. Set-up reduction and TPM programs focused on bottleneck areas.

Three managers were interviewed there: the production manager (M1), responsible for shop-floor activities; the industrial manager (M2), responsible for MS and co-ordination with other areas and the PPC manager (M3), responsible for the production planning, scheduling and control. The data collection was in May and June 1996.

7.4.2 Manufacturing Trade-offs

General View - Managers had different **views** on trade-offs in this case. M1 believed that trade-offs **resulted from changes** in system's performance requirements: *"Working under normal conditions should not cause any trouble... the problem begins when there is a need for something else in terms of variety or performance."* He believed that some trade-offs might be only **'people's perception'**. For example, on QC, *"I don't think they need to be a trade-off, but this is in people's minds and this is difficult to change"*. He thought that other trade-offs really **existed**: *"Dependability and flexibility (variety) is a trade-off in essence. If we have rigid lines we can deliver on schedule but this is more difficult with flexible lines."*

M2 **did not believe** in trade-offs *'as an OM issue'*. He believed that a system does not aim achieving 100% performance but rather *'complying with market requirements'*. Since he believed that this plant could even surpass such requirements, he did not acknowledge any (relevant) trade-off there: *"I don't believe in trade-offs... there is, for example, the idea that increasing quality increases cost. I don't think so. I think this is the opposite: the more quality you have, the lower is the cost... unless you are* *talking about perfection. If you want perfection, that (increase in quality) will be not justified, but at the level of satisfaction of the client there is no trade-off."* Nevertheless, his view on QC is compatible with the 'Economic Conformance Level' (see Chapter 3). The only difference is that he did not believe that this company needed quality performance levels beyond the ECL.

M3 had a more classical view. He, as M1, thought that some trade-offs **existed** - with varying levels of **importance** - and others did not. For instance, he did not believe that QC existed - "*increasing quality does no increase cost*" but believed that DV existed: "*This is very important... It is very difficult making many different products and being reliable in deliveries*". This view was similar to M1's view on DV.

<u>**Nature**</u> - Managers believed that trade-offs were **dynamic** and could be improved. However, they disagreed on the extent of the impact of such improvements on the performance of trade-offs. M1 believed that trade-offs could be **eliminated** if one turned the system compatible with market requirements: *"After the process is set up and working well, you don't need to sacrifice quality, speed or cost to be reliable in deliveries."* M3 believed that there was a **limit** to their improvement - they could not be eliminated: *"You can improve the trade-offs, but there is a limit... if I had to make parts to all the cars in the world, it would be almost impossible in terms of costs with machines and tools... even if set-up costs were zero."*

Managers believed that trade-offs were **contingent** on different areas, strategies and periods. For example, M1 suggested that QS was an 'extremely important' trade-off for new products. It also characterised traditional products, but was then easier to manage and thus less important. This was the same for QV across different periods: *"... this trade-off may not be as important (in the future) as it is today, but they seem to be extremely incompatible."* M3 said he thought CD did not characterise manufacturing but existed in other areas: increasing dependability increased costs with transport and storage of products.

Some trade-offs might have **related** sources of performance or importance. M1 believed that increasing product flexibility could improve both QS and QV. M3 considered production and machine flexibility as major performance factors of all trade-off involving cost, variety or dependability.

Importance Factors - Table 7-13 presents the major variables that determined the importance of trade-offs in Case D.

Importance Factor	Trade-offs Affected
Products novelty	Quality and Speed
Customer expectations	Cost and Speed Dependability and Variety

Table 7-13: Trade-offs importance factors in Case D

The recent introduction of new products (with a competitive focus on quality) seemed to have increased the importance of QS. On the same way, increasing customer expectations increased the importance of trade-offs such as CS and DV. Case D thus presented **two importance factors**. These related to the **external environment** and concerned **market and strategy variables**.

Performance Factors - Table 7-14 summarised the major variables that determined the performance of trade-offs in Case D.

Performance Factor	Trade-offs Affected
Product flexibility	Quality and Speed Cost and Speed
Production flexibility	Dependability and Variety
Machine flexibility	Trade-offs with Dependability, Cost and Variety
System's co-ordination	Cost and Variety
Set-ups	Speed and Variety, Quality and Speed, Quality and Variety, Cost and Variety, Dependability and Variety
Production management	Cost and Speed
Product development	Cost and Speed; Quality and Speed
Forecasting	Speed and Variety
Capacity management	Speed and Variety
NC machines	Quality and Speed, Quality and Variety

Table 7-14: Trade-offs performance factors in Case D

These performance factors are in three types. The first is process attributes. These include product, production and machine flexibility and co-ordination. The second concerns capabilities such as set-ups, forecasting and capacity management. The third type concerns NC machines (a resource). Case D thus had **10 performance factors,** concerning **attributes, capabilities and resources** and relating to **internal variables.**

Effects - Trade-off seemed to affect this company in two major ways:

(1) Requiring the setting of **priorities** in MS. Managers were in that occasion discussing whether to set quality or cost as priority, due to a trade-off between these variables:: "*... we can either make it faster or make it better, but not faster and better at the same time*" (M1);

(2) Generating problems in **related dimensions**. This was the case of CS: "*... the faster we make it, the more expensive it is*" (M1).

Management - People believed that they could **improve** a trade-off performance by developing better **resources** (such as NC machines and CAD) and **capabilities** (such as set-ups, inventory management and process activities). Trade-offs should also improve with better **attributes** such as reliability and flexibility. The combination of resources, capabilities and attributes to deal with trade-offs was often essential: "*We only need to build a system with the ability to deliver quality and variety*" (M3).

M2 thought that trade-offs existed but were not relevant in this company (they would be 'automatically' discarded given the right approach). One should improve trade-offs by **focusing on their sources** instead of effects. For example, he said that increasing speed alone could not justify problems in quality: "*But why is he having problems in quality? This is not because he is working faster, there is some problem behind this.*"

Managers also suggested other approaches to deal with trade-offs. M3 suggested that one could cope with CS by **reducing the importance** of variety: "*To improve this trade-off you need to define a mix of products that are really important... and to reduce your variety in this way*". M1 considered that the solution for QS relied on

finding an equilibrium between quality and speed requirements. For instance, by setting up minimum delivery times to be observed both by manufacturing and sales: "*... when we try to work faster we tend to make it without appropriate tooling, without appropriate people, etc., and that leads to quality problems as such.*"

7.4.3 Major Manufacturing Trade-offs

The most important trade-offs in Case D were QS, CS and DV. In opposition to other cases, these were quite independent and involved all MSDs from the research framework. These are following discussed.

Cost and Speed, Case D: (1) For M1, "*... the faster we make it, the more expensive it is.*" M3 also suggested a trade-off between speed and cost. For example, the firm had to pay *premium* prices if it needed materials to be delivered faster than previously negotiated with suppliers. Increasing speed might also increase costs with disruptions, machine breakdowns, overtimes and waste. (2) Managers suggested that the solution to CS was (a) **improving** the process and its management and (b) **reducing** parts variety: "*To improve this trade-off you need to define a mix of products that are really important... and to reduce your variety in this way*" (M3). (3) Managing CS required better **capabilities** such as *production management* and *product development. Product flexibility* was the most important **attribute** in this case.

Dependability and Variety, Case D: (1) M1 and M3 had similar ideas on DV in this case: "*DV is a trade-off in essence. If we have rigid lines we can deliver on schedule but this is more difficult with flexible*[9] *lines*" and "*This is very important... It is very difficult making many different products and being reliable in deliveries.*" The problem was that increasing variety reduced their ability to manage dependability. People believed that dependability had increased somehow but was still below market requirements. (2) "*To improve these, you need to optimise your set-ups and process...*

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[9] It should be noted that M1's reference to 'flexible lines' is not appropriate. Truly flexible lines should cope with variety at good dependability, quality, speed and cost levels.

this is what we have been doing with TOC (Theory of Constraints)" (M3). Management had been using *TOC* in a bid to identify and **focus** on areas that might be critical to dependability and variety performance. (3) On such critical areas, they had been **improving** *set-up methods* **(capabilities)** and thus *production and machine flexibility* **(attributes)**. In other words, they were attempting to build truly 'flexible lines', different from the kind suggested by M1.

Quality and Speed, Case D: (1) M1 qualified QS as the most important trade-off there: *"Its importance could be even more than 5 ... we can either make it faster or make it better, but not faster and better at the same time."* This importance increased with a recent introduction of many new products. New products increased the system's complexity and made it more difficult to control the quality and speed performance. (2) For M1, the solution was to set quality a **priority** over speed. He suggested defining 'minimal' delivery times to be observed both by manufacturing and sales. (3) Other people suggested **improving resources** (*NC machines*), **capabilities** (*set-ups and product development*) and **process attributes** (*product flexibility*) to make it easier dealing with QS in a context of increasing complexity.

7.4.4 Manufacturing Flexibility and Trade-offs

Table 7-15 describes the relationship between flexibility and trade-offs in Case D.

Flexibility Type	Related Capabilities/ Resources	Nature of Impact Cap./Res. → Flexibility Type	Related Trade-offs	Nature of Impact Flexibility Type → Trade-off
Product (1)	Design, CAD	CAD improved design methods and the quality and speed of new products design.	QS CS	The company needs to improve its product flexibility to introduce products with better manufacturability. That is a better combination of production speed, cost and quality. (QS, CS)
Volume (5)	Inventory management, CAM, MRP, TOC	MRP, TOC and CAM technologies improved the management of inventories and production capacity.	ALL	For M2, increasing volume flexibility means increasing knowledge and control of the system's capacity and thus of its trade-offs.
Production (4)	Set-ups, NC machines, set-up methods, TOC	NC machines and set-up reduction methods - based on TOC rules of priority setting - reduced time and cost of set-ups.	THOSE WITH D/C/V	For M3, set-up's improvement both at machine and system's level (production and machine flexibility) are the major factor behind trade-offs with dependability, cost and variety.
Machine (10)	Set-ups, NC machines, set-up methods, TOC	NC machines and set-up reduction methods - based on TOC rules of priority setting - reduced time and cost of set-ups.	THOSE WITH D/C/V	For M3, set-ups improvement both at machine and system's level (production and machine flexibility) are the major factor behind trade-offs with dependability, cost and variety.

Table 7-15: The impact of flexibility types on trade-offs: Case D

Figure 7-5 summarises the network of relationships suggested in case D.

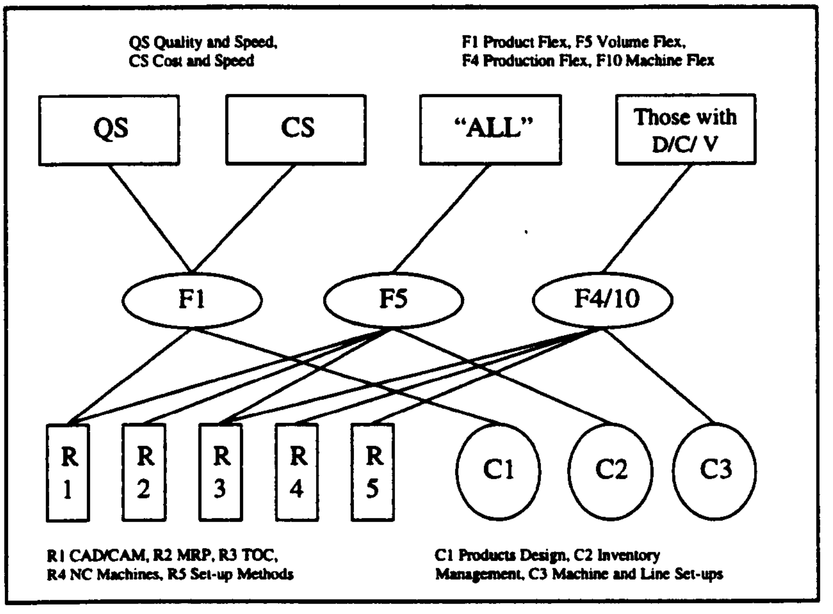

Figure 7-5: Network of flexibility types, trade-offs, resources and capabilities: Case D

7.4.5 Data Summary - Case D

Table 7-16 presents a data summary for case D.

Section	Subject	Characteristics
Company's Background	Description	Mechanical equipment (automotive components) manufacturer in South Brazil; 1300 employees on site; 110 million pounds revenues.
	Shop-Floor	Manufacturing and assembly plant; 700 operative workers.
Manufacturing Trade-offs	General View	Trade-offs as compromises; relevant/not relevant; some as human perception.
	Nature	Dynamic; limit for improvement/may be eliminated; contingent; some are related.
	Importance Factors	2; external; market and strategy variables.
	Performance Factors	10; internal; attributes, resources and capabilities.
	Effects	Priorities choice; problems to related dimensions.
	Management	Improvement; focus on system; priorities setting; reduction of importance.
Major Trade-offs	Major Trade-offs	QS, CS, QV.
	Ranking of MSDs: Importance	S & V, C, Q, D.
Manufacturing Flexibility and Trade-offs	Major Flexibility Types	Product, volume, production, machine.
	Related Trade-offs	QS, CS, others.
	Related Capabilities	Design, inventory management, set-ups.
	Related Resources	CAD, CAM, MRP, TOC, NC machines, set-up methods.

Table 7-16: Data Summary: Case D

7.5 Case E - The Brazilian Winery

7.5.1 Company's Background

<u>**Strategy**</u> - Company E was a wine, grape juice and fruits manufacturer located in South Brazil. This was a co-op of farmers set up to manufacture and distribute primary products (grapes) and by-products (wine) nation-wide and with economies of scale. The plant had 55 employees - 35 in manufacturing and 20 in management, sales and distribution. The co-op was an association of 245 families.

The company was founded in 1965, exclusively as a wine producer. However, new market trends and increasing competition - specially from Chile and Argentina - forced diversification. Wines corresponded to about 70% of revenues and they were also working with grape juice and fruits '*in natura*'.

The plant worked in a make-to-stock basis. It had 5 major distributors, while some major customers would buy directly from it. The major suppliers were the co-op farms (that do not sell their crops only to this company), while 5% of supplies value came from Uruguay. Sales in 1995 were about 3 million sterling pounds and increasing.

The company aimed to provide a wine that was 'as good as' its major competitors in the category. Since they operated in a low price band, changes in economic or market variables had usually a great impact on revenues. The recent diversification thus aimed to protect against these oscillations, the competitors and the seasonal character of wine manufacturing and sales (80% concentrated in the 1st Semester).

<u>**Shop-Floor**</u> - The plant's shop-floor was a conventional winery process. Operations had two major stages: production and bottling. There were three rigid production lines dedicated to (1) white wine, (2) red wine and (3) grape juice. Bottling lines were flexible and could cope with any product and bottle type.

Manufacturing and sales were highly seasonal and focused on the first semester. The company stored part of its production to be bottled in the second semester.

The workforce was highly specialised and skilled due to its low rotation. Most people had been working there for more than 5 years. The relationship between company and workers was facilitated by the character of the area (a small, traditional Italian-descendants village) and the community character of the co-op.

System's improvements concerned usually new process technologies. There were recent changes in the layout of the bottling and delivery areas. These saved cost and time with parts transportation and storage and were well accepted by operators.

The two managers interviewed were the General Manager (M1), responsible for marketing and finances and the Production Manager (M2), responsible for the production planning and supervision. The data collection was in May 1996.

7.5.2 Manufacturing Trade-offs

General View - Managers in this company had a good understanding of the idea and implications of trade-offs. They **viewed** trade-offs as compromises between manufacturing objectives. They believed that trade-offs **existed** and had **different levels of importance**. The only exception was M1's view on QC. In spite of believing in its existence, he suggested that people would give more importance to this trade-off that necessary. QC was **'in people's minds'**. OM had been trying to change this view, but he thought this would take time.

Maybe the ease of people to understand trade-offs came from the fact that this was a process plant where MSDs and their relationships would be easily known. Trade-offs such as QS and QV were daily issues relating to key MS aspects such as process scale, batch sizes and products variety. Managers were struggling to maintain the company's competitiveness. Their success depended largely on decisions on these trade-offs.

Finally, it seems interesting noting how the analysis of a trade-off might vary depending on the variables taken in consideration. For M2, SD was an important trade-off if considering speed 'time to deliver'. However, there should be no trade-off here if speed referred only to 'production lead-time'.

__Nature__ - Trade-offs were seem as **dynamic** as they might be affected by managerial action. For instance, QD was an important problem there: 'rushing' to meet delivery dates usually harmed the products' quality. However, the company had been able in the past to improve this trade-off: "*The introduction of enzymes and catalysts 15 years ago brought this relationship into a new stage, but now this is static again*" (M1). Thus, QD was seen as dynamic, although there was a **limit** for its improvement.

Managers saw trade-offs as **contingent** on market and process variables such as products' nature, process technology and workforce skills. Unfortunately, this seemed to be against then. They considered wine a 'difficult' product to process and control and thus subject to strong trade-offs. They believed that trade-offs such as QV and QD did not have the same impact on grape juice as on wine. As M2 saw QV, "*With wine, the more you change the process, the more quality problems you have.*" They often referred to such trade-offs as being **related.** For example, M2 said that SV was similar to QV because they had the same source: "*... again, the more changes we have to do, the more we waste time with set-ups, cleaning, inspections, etc.*"

__Importance Factors__ - Table 7-17 summarised the major variables that determined the importance of trade-offs in Case E.

Importance Factor	Trade-offs Affected
Market requirements	Quality and Variety
Level of competitiveness	Quality and Speed
Proximity to final customers	Quality and Dependability
Number and variety of orders	Quality and Dependability

Table 7-17: Trade-offs importance factors in Case E

Competitiveness levels and market requirements where the major factors behind the importance of QV and QS. Importance factors for QD were the company's proximity to final customers (major final customers might even order directly) and the number and variety of sales orders. These increased the importance of dependability to an extent that it could affect the products quality, as explained above. Case D thus had **four importance factors** relating to the **external environment** and concerning **market and strategy variables**.

<u>**Performance Factors**</u> - Table 7-18 summarises the major variables that determined the performance of trade-offs in Case E.

Performance Factor	Trade-offs Affected
Machine flexibility	Quality and Variety, Speed and Variety
Volume flexibility	Quality and Variety, Speed and Variety, Quality and Speed, Quality and Dependability
Rerouting flexibility	Quality and Speed, Quality and Dependability
Process reliability	Quality and Speed
System's co-ordination	Quality and Dependability
Inventory management	Quality and Dependability
Supply management	Quality and Dependability
Sales management	Quality and Dependability
Production planning and control	Quality and Dependability
Process capabilities	Quality and Speed
Machine set-ups	Quality and Variety, Speed and Variety
Workforce skills	Quality and Speed
Process technology	Quality and Dependability; Quality and Variety, Speed and Variety; Quality and Speed
Layout	Quality and Dependability

Table 7-18: Trade-offs performance factors in Case E

These factors are divided into three types. The first is process attributes, concerning flexibility, reliability and co-ordination. The second is capabilities such as supply and manufacturing management and set-ups. The third type is resources such as workforce skills and process technology. Case E thus had **14 performance factors** relating to **process attributes, capabilities and resources** and concerning **internal variables**.

<u>**Effects**</u> - Trade-offs seemed to affect this company in 3 ways:

(1) Forcing setting **priorities** in performance - People found it possible making either cheap or quality wines, but not both. Product and process forces lead to trade-offs such as QC and SV that, in their view, made it impossible being good in all areas;

(2) Increasing problems in **one dimension** caused by failures (or limitations) in relating dimensions. For M1, the chronicle low speeds of labelling machines often lead to quality problems as well: *"If we increase its speed, its performance drops and many labels are stuck in wrong positions";*

(3) Limiting the ability to hire the full **potential performance** of the system. This plant had both the volume capacity and market demand to produce additional wine varieties. However, because of a QV trade-off (set-up changes harm quality) they had to limit the output to a few varieties. Even though these varieties were good sellers, they did not hire more than 80% of the capacity.

Management - Managers suggested dealing with trade-offs in two ways. First, by **improving** their performance by developing better process **resources** or **capabilities**. One example is M1's view on QD, presented above: "*The introduction of enzymes and catalysts 15 years ago brought this relationship into a new stage, but now this is static again.*" This means that the introduction of a new resource (enzymes and catalysts) and the development of a better capability (the 'use' of such enzymes and catalysts in the process) improved the relationship between quality and dependability - leading to better performance in both areas, even though QD remained a trade-off.

Second, they would deal with trade-offs through **compensation**. This is to make up for competitive damages caused by a trade-off with benefits in another area. M2 said that DC had ever existed but did not use to be important because *"Customers would even pay a premium price to get the product on schedule."* Higher prices paid for the cost of 'extra' dependability.

7.5.3 Major Manufacturing Trade-offs

The major trade-offs in Case E - QD, QS, QV and SV - are following discussed.

Quality and Dependability, Case E: (1) The problem with QD was that different wine batches might require different lengths of time to mature. Imposing delivery dates on this context was very difficult. Increasing the dependability performance would affect the products' quality as they might be delivered before they had matured. This trade-off did not use to be important. However, an increase in the number and variety of customers' increased dependability requirements. Meeting delivery dates was each time more important in this market. (2) **Improving** this trade-off was possible but might require technical advances that could happen only from time to time: "*The introduction of enzymes and catalysts 15 years ago brought this relationship into a new stage, but now this is static again*" (M1). Another option was to limit dependability promises to levels that would not affect the (**priority**) quality performance. (3) Improvements in this trade-off had been due to better **resources** (*workforce skills, new process technology, new layout*) and management **capabilities** (*supply, inventories, sales and PPC management*). This increased **attributes** such as *system's co-ordination and volume and rerouting flexibility*.

Quality and Speed, Case E: (1) The problem with QS was similar to QD. Besides, M1 told of this trade-off in the bottling, labeling and packaging areas. The best example was with the labelling machine: "*If we increase its speed, its performance drops and many labels are stuck in wrong positions.*" People in those areas found it difficult guaranteeing good quality at increasing speeds. (2) For M1, the solution was to replace this machine with some more advanced technology and to qualify operators to work better and faster. (3) This relied on better **resources** (*new machine*), **capabilities** (*training*) and **attributes** (*reliability, volume and rerouting flexibility*).

Quality and Variety, Speed and Variety, Case E: (1) "*With wine, the more you change the process, the more quality problems you have*" "*... the more changes we have to do, the more we waste time with set-ups, cleaning, inspections, etc.*" (M2). Process set-ups increased the risk of contamination caused by residues of one variety in contact to another, in case they were processed by the same equipment. This required increasing the cost and time with cleaning and inspections as well as scrapping part of the first batch. This was specially important with big equipment. (2) For M2, one solution was to increase sales to make it possible working with bigger batches and fewer set-ups, thus **reducing the importance** of variety. Another solution was to **improve** the ability to make set-ups without affecting quality. Third, one might evaluate the economic advantage of implementing smaller equipment dedicated to single varieties, thus **minimising** set-ups. Finally, the standardisation of label sizes could **eliminate** these trade-offs in the labelling area. (3) The second solution depended on increasing *machine and volume flexibility* (**attributes**) due to improving *set-ups* (**capability**). The third relied on small scale *process technology* (**resource**).

7.5.4 Manufacturing Flexibility and Trade-offs

Table 7-19 shows the relationship between flexibility and trade-offs in Case E.

Flexibility Type	Related Capabilities/ Resources	Nature of Impact Cap./Res. → Flexibility Type	Related Trade-offs	Nature of Impact Flexibility Type → Trade-off
Rerouting (9)	Layout, Parts transportation	New layout reduced time and cost of transportation increasing rerouting flexibility.	QS QD	Better rerouting flexibility allows working with increasing speed and dependability with no harm to products quality.
Volume (5)	Inventory management, Layout, Process technology	New process technology and layout improved inventory facilities and management and capacity management.	QS QD QV SV	Better volume flexibility allows working with increasing speed and dependability with no harm to products quality (QS, QD). Volume flexibility is necessary to allow working with changing variety/volumes with no harm to speed or quality performance (QV, SV).
Machine (10)	Process technology, set-ups	New technology reduced set-up times and improved range of activities/parts processed.	QV SV	Machine flexibility allows working with changing variety/volumes with no harm to speed or quality performance.

Table 7-19: The impact of flexibility types on trade-offs: Case E

Figure 7-6 summarises the network of relationships suggested in case E.

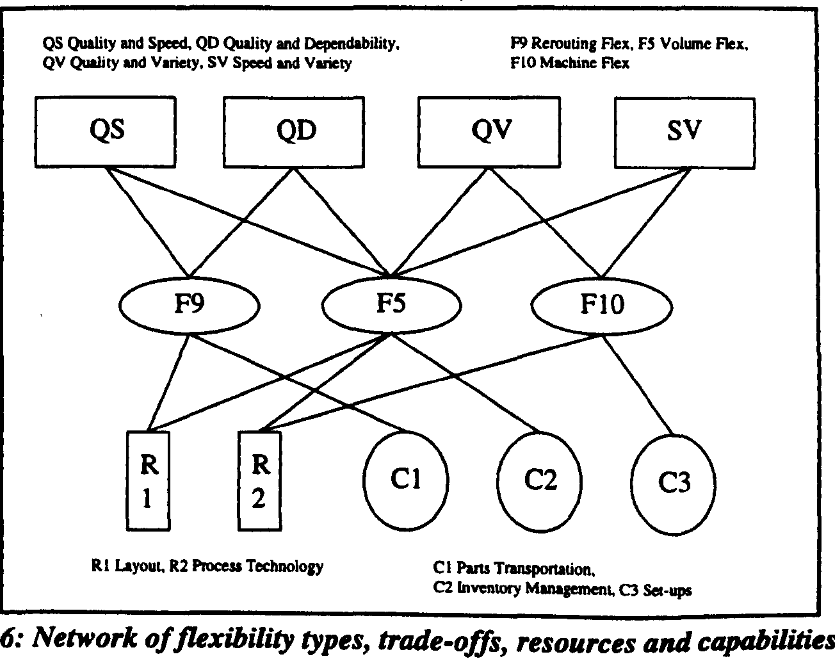

Figure 7-6: Network of flexibility types, trade-offs, resources and capabilities: Case E

7.5.5 Data Summary - Case E

Table 7-20 presents a data summary for case E.

Section	Subject	Characteristics
Company's Background	Description	Wine and juice manufacturer in South Brazil; 55 employees on site; 3 million sterling pounds revenues.
	Shop-Floor	Manufacturing and assembly; 35 employees.
Manufacturing Trade-offs	General View	Compromises; relevant; some in people's minds.
	Nature	Dynamic; limit for improvement; contingent; related.
	Importance Factors	4; external; market and strategy variables.
	Performance Factors	14; internal; attributes, capabilities and resources.
	Effects	Priorities setting; problems in related dimensions; limit rent of potential performance.
	Management	Improvement; priorities setting; importance reduction.
Major Trade-offs	Major Trade-offs	QS, QD, QV, SV.
	Ranking of MSDs: Importance	Q, V, S, D, C.
Manufacturing Flexibility and Trade-offs	Major Flexibility Types	Rerouting, volume, machine.
	Related Trade-offs	QS, QD, QV, SV.
	Related Capabilities	Parts transportation, inventory management, set-ups.
	Related Resources	Layout, process technology.

Table 7-20: Data Summary: Case E

7.6 Chapter Conclusions

Chapter 7 presented the within-case analysis of the data collected in five companies. Each within-case analysis was a case study and discussed four major subjects: (1) company's background - concerning its strategy, structure and shop-floor; (2) manufacturing trade-offs, relating to their nature, sources, effects and management; (3) trade-offs analysis and management, concerning major trade-offs and the managerial approaches to deal with then and (4) manufacturing flexibility and trade-offs, concerning the relationship between flexibility and trade-offs.

The case studies have all been presented within the same structure to emphasise comparative variables and to fit in the theoretical framework defined for this research. The data sources were interviews, field observations and secondary documents, following the strategy described in previous chapters. The following chapter presents the cross-case comparison of these data.

Chapter 8 - Cross-Case Analysis

Chapter 8

Cross-Case Analysis

Introduction

The cross-case analysis compares the data from the different case studies. It points out the major similarities and differences between those cases. This comparison should stress some major ideas to be further discussed in the next chapter. Comparing different case studies is not an easy task. Different quantities and qualities of data on different subjects across the cases can make this difficult - even considering that the data collection and analysis of all the cases have a common framework. Besides pointing out the similarities and differences across the cases, the researcher has to identify the main reasons behind them and, what is more important, their ability to ground (generalisable) research findings. Such ability is assessed by comparing these findings with the research data and literature (in the following chapter).

Chapter 8 is organised as following. Section 8.1 discusses the major similarities across the cases. Section 8.2 discusses the major differences across the cases. Section 8.3 assesses the strength of the propositions defined along the research framework in Chapter 4, since the analyses in Chapters 7 and 8. Section 8.4 is the conclusions.

8.1 Major Similarities

Companies' age - All the case companies were at least 20 years old (see Table 8-1). The long experience on their businesses benefited the investigation of such a complex issue as manufacturing trade-offs. Most people interviewed had a good knowledge of their companies' strategy, operations and performance. This knowledge backed the assessment of issues such as the importance and performance of MSDs, the impact of new technologies and methodologies on trade-offs and changes in the performance and importance of major resources, capabilities and trade-offs.

	Case A	Case B	Case C	Case D	Case E
Data Collection					
Place	Company Site (Midlands, UK)	Company Site (North Wales)	Company Site (South Brazil)	Company Site (South Brazil)	Company Site (South Brazil)
Date	March-April 1996	July 1996	May-June 1996	May-June 1996	May 1996
Interviewees	Design Eng. Manager Production Mngr.	Production Mngr.; Quality Mngr; Cell Manager.	PPC Mngr. (1); PPC Mngr. (2); IT Manager.	Production Mngr.; Industrial Mngr; PPC Manager.	General Mngr.; Production Manager.
Foundation					
Year	1915	1900	1971	1974	1965
Local	USA	UK	Brazil	Brazil	Brazil
Employees					
Site: Shop-Floor	550	120	2800	700	35
Site: Office	550	50	700	600	20
Site: Total	1100	170	3500	1300	55
Country	1500	10000	8000	3000	---
World	54000	20000	---	20000	---
Economic Characteristics					
Manufacturing Business	Mechanical Equipment	Plastics Packaging	Shoes	Metal-Mechanical (Automotive Parts)	Wine, Grape Juice and Fruits
Product Lines (Turnover Share)	A (50%) B (35%) C (15%)	A (65%) Others (35%)	A (60%) B (40%)	A (100%)	A (70%) B (23%) C (7%)
Layout Types	Assembly Line	Process	Job-Shop	Job-Shop, Assembly, Cells	Process
Production Cycle	Assemble-to-Order	Make-to-Order	Make-to-Stock Make-to-Order	Make-to-Stock Make-to-Order	Make-to-Stock
Number of Primary Clients	100 Dealers	15 (90% of Value)	3,000 Distributors	4 Car Makers	5 Distributors
Number of Major Suppliers	20 (90% of Value)	25 (75% of Value)	5 (55%)	10 (50%)	245 Farms
Turnover					
1995 (000's GBP)	200,000	20,000	200,000 (approx.)	110,000	3,000
Trend for 1996	Increasing	Increasing	Increasing	Increasing	Increasing
Distribution of Sales	UK (10%); Europe (70%); World (20%)	UK (60%); Europe (40%)	Brazil (85%); World (15%)	Brazil (85%); World (15%)	RS State (20%); Brazil (80%)
Distribution of Purchasing Value	UK (50%); Europe (30%); World (20%)	UK (50%); Europe (25%); USA (25%)	Brazil (95%); World (5%)	Brazil (90%); World (10%)	RS State (95%) Uruguay (5%)
Strategy and Structure					
Number of Organisation Levels	4 (Site and UK); 6 (World)	4 (Site); 10 (UK and World)	5 (Site); 7 (Brazil)	7 (Site); 9 (Brazil and World)	3 (Site)
Major Competitive Objectives	Quality (Reliability) and Variety	Meeting Quality, Cost and Speed Specifications	Market Share, Cost, Variety	Quality (Reliability) and Cost	Quality and Cost
Strategy Process: Local vs. Global	Divisional	Global	Global	Global and Local	Local
Strategy Formulation	5 years strategy annual review	5 years strategy annual review	5 years strategy annual review	5 years strategy annual review	5 year strategy periodic review

Table 8-1: The case companies: Background data

The maturity of these companies improved the quality of the research data and the process of data collection and analysis itself. The evidence provided seemed as valuable as expected and usually concerned long periods of operation. Differences between people's ideas in the same subject were usually of 'personal' instead of 'factual' nature, i.e. subjective instead of objective.

Number of major product lines - The number of major product lines in the cases is another aspect that improved the data collection and analysis process. One or two lines corresponded always to at least 85% of sales (see Table 8-1). This is due to the level of the data collection (plant level) and the nature of the companies.

Case A consisted in three assembly lines, where lines A and B corresponded to 85% of revenues. Case B consisted in a single process plant where one product corresponded to about 65% of revenues. Case C consisted in three (similar) focused factories that were all investigated and analysed as in one context. Case D was a metal-mechanical plant focused on one major product line. Finally, Case E was a process plant where one product corresponded to about 70% of revenues.

This factor improved the scope of the data collected in the companies. Most data from observations and interviews refereed to entire production systems. Data concerning the cases' particularities were evident in the within-case analysis. This ability to collect data corresponding to 'whole' production systems ensured that all the cases were investigated within the same level and variables. This improves the validity of cross-case comparisons and the generalisability of corresponding research findings.

Major competitive objectives - The companies' major competitive objectives were similar. All the cases indicated quality as their major objective; this was followed by cost in four cases (see Table 8-1). The other objectives that appeared (variety in Cases A and C and speed in Case B) always came after quality or cost. Not surprisingly, trade-offs involving quality had a major importance in all the companies and were the most frequently investigated.

However, as will be discussed in Section 8.2, the major trade-offs of each company varied largely and often involved dimensions not quoted in their mission. The case data suggests an explanation for this. It seems that there is a difference between what managers quoted as the 'firm's competitive mission' - with their correspondent objectives - and the actual strategic importance of these dimensions. Quality and cost appeared in the companies' mission in part because they were important but also because they seemed more familiar than other dimensions such as speed and dependability. When people described the strategic importance of each dimension in separate, variety, speed and dependability could be as important as quality and cost.

The relevance of trade-offs to operations management - In all the cases, trade-offs were seem by most people as a major issue to OM. The idea of trade-offs as compromises between different manufacturing objectives or dimensions was present in all the cases. The few exceptions were M2 in Case D, that proposed that trade-offs existed but did not impede achieving the performance levels required by the market, and M2 in Case C, that viewed trade-offs as conflicts between different areas such as design, manufacturing, scheduling and sales. The other managers followed the 'compromises' approach.

The cases provided a series of ideas corroborating that concept and importance of trade-offs. In Case A, trade-offs were important because that company needed to compete in different dimensions and these were often incompatible. In Case B, QC, QS and QV were in the core of major MS decisions regarding aspects such as the nature of the process, the number of people in shop-floor and their organisation. In Case C, the company needed to achieve high performance in many different dimensions simultaneously. As M2 suggested, *"... the problem is global and can not be divided in compartments like this."* In Case D, changes in industrial competition increased the performance requirements in many dimensions, causing major problems to OM: *"Working under normal conditions should not cause any trouble... the problem begins when there is a need for something else in terms of variety or performance"* (M1); *"Dependability and flexibility (variety) is a trade-off in essence.*

If we have rigid lines we can deliver on schedule but this is more difficult with flexible lines" (M3). Finally, Case E had major problems to guarantee quality and dependability performance in a context of increasing variety. Trade-offs such as QV, SV and QD were behind their major competitive weaknesses.

The nature of manufacturing trade-offs - Perhaps surprisingly, the major trade-offs in the cases had quite similar characteristics. First, they were usually seen as contingent. That is managers suggested that the nature of relationships between different MSDs depended on a number of variables. Some of these variables were external and concerned strategy and market factors. Some were internal and concerned the resources and capabilities available in the system. For example, the importance (impact of strategy) and performance (strength of the correlation) of the QV trade-off in Case C depended on (a) external factors such as the number of market niches where the firm operated and the strength of its competitors and (b) internal factors such as their abilities on forecasting, product development and product flexibility.

Second, as they were contingent on a number of factors, trade-offs could usually change after management or other forces changed these factors. These trade-offs were dynamic. For example, *"Quality and speed is still a trade-off, but I would say it has improved"* (M1, Case A); *"By putting a CIM system enabled us to track our quality (on-time) and it made the trade-off between quality and speed weaker"* (M1, Case B); *"Since we created the work teams, these things improved..."* (M2, Case C); in Case D, a new CAD system improved the relationship between the quality and speed of design activities; in Case E, the introduction of enzymes in the process improved the quality and dependability of the wine process.

Finally, all the cases provided examples of groups of trade-offs that (1) shared the same performance or importance factors (see definition above); (2) had similar effects on management and strategy and/or (3) were suitable to similar improvement strategies (measures to improve the correlation between their variables). For example, in Case B, QC, QS and QV had similar performance factors and effects and were suitable to similar management measures. In Case C, CS, CD and CV had similar sources and effects. Cases A, D and E also provided a series of examples here. Such groups of trade-offs had usually one dimension in common. This seems to be the major reason for their relatedness. However, there were exceptions. In Case E, for example, volume flexibility was a performance factor of both SV and QD.

The importance versus the performance of trade-offs - The cases suggested that the importance of trade-offs was different from their performance. The importance of a trade-off is here defined as its impact on manufacturing strategy and management. The performance of a trade-off is defined as the strength of the correlation between its variables. Since trade-offs represent a negative correlation, high performance levels correspond to weak trade-offs and low performance levels correspond to strong trade-offs. The cases suggested that the performance and importance of trade-offs were mostly independent.

The factors that determined their importance were always external and concerned market and strategy variables. For example, customer expectations and industrial competitiveness determined the importance of major trade-offs in most cases. The factors that determined their performance were always internal and concerned the range or resources, capabilities and attributes of the system. For example, process technologies and methodologies (resources), shop-floor abilities (capabilities) and flexibility (attributes) related to the performance of major trade-offs in all the cases.

The investigation focused on the most important trade-offs of each case. These data (on Sections 7.2.3, 7.3.3, 7.4.3, 7.5.3 and 7.6.3) suggest that the performance of trade-offs varied largely and was independent from their importance. For instance, QC and QS were equally the most important trade-offs of Case A but their management lead to quite different results. While QC had not been solved (managers still believed they had to sacrifice cost to improve quality), QS was in a better situation: "*Quality and speed is still a trade-off, but I would say it has improved.*" (M1).

The role of flexibility in the management of trade-offs - Developing flexibility types could be linked with the successful improvement of trade-offs in all the cases. Flexibility always improved their ability to work with one or both variables of major trade-offs. It improved the correlation of those variables. For example, the QD trade-off in Case A improved due to increasing labour and process flexibility (Section 7.1.4). They increased the firm's ability to make quality products out of an increasing variety of materials and production sequences thus minimising stoppages that harmed dependability. Machine, process, delivery and production flexibility improved QS, SV and CV in Case B (Section 7.2.4). Process, labour, product, machine and volume flexibility improved Cases C's ability to deal with QC, QV, SV and CV (Section 7.3.4). In Case D, product, volume, production and machine flexibility could be linked with all their major trade-offs (Section 7.4.4). Finally, rerouting, volume and machine flexibility improved QS, QD, QV and SV in Case E (Section 7.5.4).

Among the eleven flexibility types used in the research, only expansion flexibility did not relate to any trade-off in any case. The types most frequently linked with trade-offs were product, volume, process and machine flexibility. Along with expansion and rerouting, these are the most common flexibility types in the literature (Section 2.2.1).

Another aspect of flexibility that was similar across the cases was the need to distinguish between flexibility and variety when assessing trade-offs. This was not anticipated in the research framework. Flexibility is a multidimensional variable including dimensions such as cost and speed in its formation. It is a function of variety and some other variable. Thus, assessing trade-offs such as *flexibility and cost* or *flexibility and speed* was illogical, as even some managers suggested. It was more accurate assessing trade-offs between *variety* and other dimensions. Flexibility was regarded as a system's attribute and had the role described above. Fortunately, this became obvious in the first case and was then applied with success in the other cases.

8.2 Major Differences

Type of manufacturing process - The companies had two different process types. Cases B and E were high volume/low variety systems (process systems). These were technology-intensive companies with 120 or fewer employees in the shop-floor. They are here called *process companies.* Cases A, C and D were medium volume/high variety systems (batch systems). Their technology was mostly stand-alone and they had among 550 and 2,800 employees in the shop-floor. They are here called *batch companies.* Figure 8-1 shows the Product versus Process Matrix of the 5 companies.

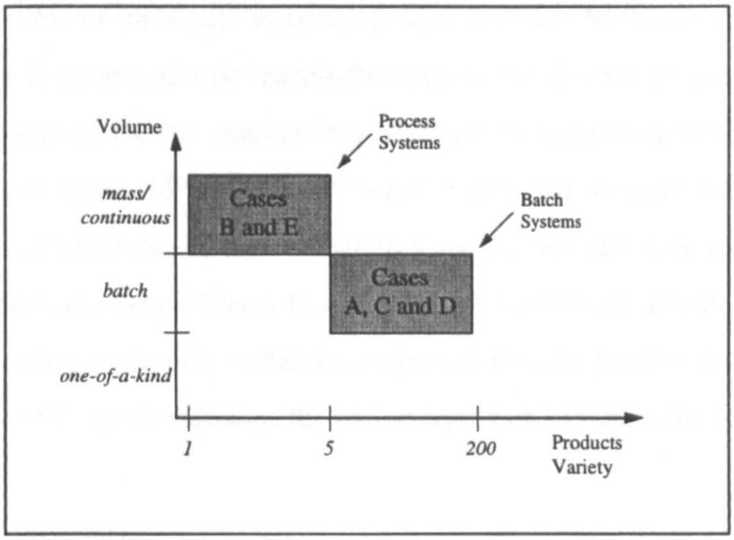

Figure 8-1: Product vs. Process Matrix of the case companies

The variable 'type of process' had been defined at the beginning of the study and guided the choice of the case companies. The researcher believes the mix of 2 process and 3 batch companies places a good balance between the validity and generalisability of findings. Besides, both the process and batch companies were divided into Brazilian and British (Table 8-2) to permit the identification of the origins of further differences between the cases.

Origin/Manufacturing Type	Process	Batch
Brazilian	*Case E*	*Cases C and D*
British	*Case B*	*Case A*

Table 8-2: Case companies: Origin and manufacturing type

The understanding of trade-offs - It seems that the idea of trade-offs was more easily understood in the process companies than in the batch companies. Managers in the process companies could usually describe and give examples of trade-offs with some ease. For example, "*By putting a CIM system enabled us to track our quality and it made the trade-off between quality and speed weaker.*" (M1, B) and "*With wine, the more you change the process, the more quality problems you have*" (M2, E).

In the batch companies, specially Cases D and C, managers often had different views of the concept or nature of trade-offs. As discussed above, the few exceptions to the most common view of trade-offs as compromises between MSDs were in Cases D and C. M2 in Case D proposed that trade-offs existed but did not impede achieving the performance required by the market. M2 in Case C suggested that trade-offs were conflicts between areas. M3 in Case D found it difficult to understand and describe trade-offs. Such examples did not appear in Case A, but this was an assembly plant divided in three lines, while Cases C and D had a functional layout. It may be more difficult to visualise trade-offs in batch companies than in process companies, just as it may be more difficult to visualise the performance of MSDs in the former type.

Most important manufacturing trade-offs - As expected, the firms' most important trade-offs were different across the cases (Table 8-3). Importance is the impact of trade-offs on the MS. These trade-offs included all but two types (SD and CD out) and all MSDs defined in the framework. Differences between the importance levels of trade-offs seemed to relate more to strategy and market variables than to the companies' origins or process types.

The number of times each dimension appears as part of major trade-offs in the case studies is in the last row of the table. Those frequencies suggest what is the relative importance of each dimension as part of trade-offs. This is their general level of incompatibility with other dimensions. According to these data, quality and variety seem to be the most incompatible dimensions in the cases, followed by speed. Cost and dependability seem to be the most compatible dimensions there. These data agree with Ferdows and De Meyer data (1990, p. 180)[1]. If these data could be generalised, they would suggest that the Sand Cone Model as proposed by these authors does not reflect the reality of OM. The Sand Cone Model assumes that quality is the most *compatible* dimension, followed by dependability, speed and cost.

Case/Trade-offs	QC	QS	QD	QV	CS	CD	CV	SD	SV	DV	Frequency
Case A	A	A	A	---	---	---	---	---	---	---	3
Case B	B	B	---	B	---	---	B	---	---	---	4
Case C	---	---	---	C	---	---	C	---	C	C	4
Case D	---	D	---	---	D	---	---	---	---	D	3
Case E	---	E	E	E	---	---	---	---	E	---	4
frequency of each trade-off	2	4	2	3	1	0	2	0	2	2	18
frequency of each dimension	Q	11	C	5	S	7	D	4	V	9	

Table 8-3: Summary of most important trade-offs

Strategies to deal with trade-offs - The strategies of management to deal with major trade-offs varied across cases. Managers might deal with a trade-off in two major ways. First, they could improve its performance. This is focus on the performance of its variables. For example, M3 in Case C suggested improving the QV trade-off by improving the system: "*We only need to build a system with the ability to deliver quality and variety*". Second, they could reduce the importance of the trade-off. This is to focus on the strategic importance of its variables. For example, M2 in Case C suggested coping with DV by setting dependability as priority: "*What we try to do here is to avoid changing the machines schedules and to minimise the number and duration of set-ups to be able to deliver on time...*".

Moreover, the cases suggested that improving the performance or reducing the importance of trade-offs could be achieved by different ways. Cases A, D and E suggested setting priorities in MS. Cases B, D, and E suggested reducing the competitive importance of one dimension. Cases A, C, and E suggested compensating the trade-off through other benefits. This is further discussed in the next chapter.

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[1] Ferdows and De Meyer's (1990, p.180) data were opposed to the ideas in the Sand Cone Model.

Manufacturing trade-offs and human perception - Managers in Cases B, D, and E suggested that some trade-offs could be important only in terms of 'human perception'. They believed they had to cope with such trade-offs not because they were actually important, but because other people (usually operators) would suggest that they were. For example, *"I don't think they (QC) need to be a trade-off, but this is in people's minds and this is difficult to change"* (M1, Case D) and *"You actually find that, as soon as you say 'speed' to people, the actual reaction is that quality will go down; this is a human element, they don't want to increase speed, they think things will be hard to follow."* (M1, Case B). These trade-offs had also to be dealt with, but they required different types of strategies than 'real' trade-offs.

Naturally, managers themselves were bound to believe in some trade-offs that other people might not see as real. However, since dealing with trade-offs was *their* role, the way *they* saw trade-offs was usually the main criterion for defining trade-offs management strategies. Thus the choice and implementation of these strategies depended mostly on the way that managers acknowledged trade-offs. This aspect characterised companies in Great Britain and Brazil along process and batch manufacturing types.

8.3 Analysis of Research Propositions

The research propositions defined in Chapter 4 aimed to ground the data collection and analysis process, as discussed in Chapters 5 and 6. This section aims to re-examine those propositions to assess their validity and fitness to the data analysis in Chapters 7 and 8. Along with the data analysis, these 'improved' propositions will ground the research results discussed in Chapter 9.

WP1 - Manufacturing trade-offs are contingent. *(New, 1992; Slack, 1991)*: Confirmed. The importance and performance of trade-offs varied across companies and even across different periods and areas in single companies. Trade-offs were contingent on a series of performance (resources, capabilities and attributes) and importance factors (market and strategy variables). These factors might be either independent or dependent of managerial actions. Independent factors required reactive strategies and dependent factors require proactive strategies to cope with trade-offs. Reactive strategies adjust/adapt the operations to the effects of trade-offs. Proactive strategies improve/change the nature of trade-offs. These are discussed in Chapter 9.

WP2 - Manufacturing trade-offs are dynamic. *(Skinner, 1992; Slack, 1991; Hayes and Pisano, 1994)*: Confirmed. Trade-offs were dynamic as their importance and performance factors changed overtime. This was confirmed in all the cases. The interviewees' ideas differed on the extent to which managerial actions can change trade-offs positively. Some believed management actions could eliminate trade-offs; others believed there was a limit to their improvement; one suggested trade-offs were independent of management actions. It sounds reasonable to propose that management can positively improve trade-offs, as has been discussed above. However, further discussion is necessary as to which strategies can be effective in different contexts.

WP3 - Production capabilities act as trade-offs pivots. *(Stalk, Evans and Shulman, 1992; Filippini, Forza and Vinelly, 1995)*: Not confirmed. The role of capabilities (and of resources and attributes) in trade-offs management appears to be more complex than this proposition suggests. The performance of trade-offs definitely depended on the range, strength and integration of their related resources, capabilities and attributes. However, the case studies often suggested that the relationships between these variables were in two stages: resources and capabilities affected attributes and attributes affected trade-offs. It may be more appropriate considering attributes (such as flexibility, reliability, capacity and co-ordination) as trade-offs pivots and resources and capabilities as the bases of trade-offs. If one proposes that raising pivots improves trade-offs, one has to suggest how then should be raised. This seems to be the role of capabilities and resources.

WP4 - The major benefit of new technologies and methodologies is improving production capabilities that will improve trade-offs. *(Skinner, 1992; Roth and Miller, 1992; Hayes and Pisano, 1994)*: Confirmed (considering that capabilities are in the base of trade-offs rather than in the pivot). As discussed in WP3, the cases suggested that new technologies and methodologies (resources) combined with capabilities to base trade-offs. New resources might sometimes change capabilities and should always change the system's attributes. For example, a new assembly machine might either increase the assembly capacity (attribute) without changing the operators' abilities (capabilities) or affect both the capacity and the way people worked. In both cases, improving attributes (pivots) should improve trade-offs. However, in the second case this impact was reinforced by the improving capabilities.

Although this issue has been investigated in some extent, no distinction could be made between 'old' and 'new' technologies. Hence it seems difficult assessing this particular aspect of the proposition. What can be proposed is that the effectiveness of technologies and methodologies depends on their impact not only on attributes but also on capabilities and that they seem more effective when they affect both capabilities and attributes.

WP5 - Flexibility capabilities are the most influential to manufacturing strategies. *(Hayes and Pisano, 1994; Chen, Calantone and Chung, 1992; Schroeder et al., 1995)*: Inconclusive. The investigation focused more on flexibility than on any other type of capabilities. Thus comparing the effectiveness of flexibility against other types would be inappropriate. On the other hand, the investigation provided a good knowledge of flexibility in the context of trade-offs. This knowledge suggests that the role of flexibility in MS and trade-offs improvement is important. Nearly every flexibility type could be related to the improvement of major cases' trade-offs. Some of these did not even include variety - obviously the variable best related to flexibility.

8.4 Chapter Conclusions

Chapter 8 presented the cross-case analysis of the data collected in five companies. It highlighted their major similarities and differences between these cases. This analysis is one of the basis of the results to be discussed in the next chapter.

The major similarities and differences in this chapter concern the following aspects:

Major Similarities:

- *Companies' age* - All the companies were at least 20 years old;
- *Number of major product lines* - All the companies had few major product lines;
- *Major competitive objectives* - The major competitive objective of all the companies was quality; this was followed by cost in four companies;
- *The relevance of trade-offs to operations management* - Trade-offs were a major OM issue in all the cases;
- *The nature of manufacturing trade-offs* - Trade-offs were seem as contingent, dynamic and with related characteristics in all the cases;
- *The importance versus performance of trade-offs* - The performance and importance of trade-offs were independent in all the cases;
- *The role of flexibility in the management of trade-offs* - Flexibility had a role in improving trade-offs in all the cases; variety was the variable of trade-offs.

Major Differences:

- *Type of manufacturing process* - Two case companies were process systems and three were batch systems. There were both process and batch companies among the Brazilian and British companies;
- *The understanding of trade-offs* - Trade-offs seemed more easily understood in the process companies than in the batch companies;
- *Most important manufacturing trade-offs* - The most important trade-offs varied across cases due to different market and strategy variables;

- *Strategies to deal with trade-offs* - Strategies to deal with major trade-offs varied across cases;
- *Manufacturing trade-offs and human perception* - Managers in Cases B, D and E viewed some trade-offs as human perception; this was not the case in A and C.

The analysis of the research propositions from Chapter 4 lead to the following results:

- *WP1 - Manufacturing trade-offs are contingent.* Confirmed. Trade-offs were contingent on a series of factors. Their performance and importance varied across companies and across different periods and areas in individual companies;
- *WP2 - Manufacturing trade-offs are dynamic.* Confirmed. The importance and performance of trade-offs might change and be changed overtime;
- *WP3 - Production capabilities act as trade-offs pivots.* Not confirmed. Production capabilities seemed the base of trade-offs. Production attributes seemed to assume the role of pivots;
- *WP4 - The major benefit of new technologies and methodologies is improving production capabilities that will improve trade-offs.* Confirmed. The impact of new and improving resources might be broader as they influenced the performance of an increasing range of capabilities and attributes;
- *WP5 - Flexibility capabilities are the most influential to manufacturing strategies.* Inconclusive. Manufacturing flexibility had a major impact on improving trade-offs and the MS. However, this impact was not compared in the cases with other types of attributes such as capacity, reliability or co-ordination.

As has been said, the following chapter will present and discuss the results of this research, taking in consideration this data analysis, the research framework and the literature presented in previous chapters.

Part IV - Results and Conclusion

Part IV is the final part of this research. It concerns the research findings and conclusion. The research findings combine the research data with the literature and the impressions and beliefs of the investigator. They establish a series of propositions that may extend the knowledge about manufacturing trade-offs. This chapter is called 'The Management of Manufacturing Trade-offs' since this is the major subject of this research. The conclusion aims to summarise the major research findings and to suggest some topics for further research. Part IV is divided into two chapters:

Chapter 9

The Management of Manufacturing Trade-offs

Chapter 10

Conclusion

Chapter 9 - The Management of Manufacturing Trade-offs

Chapter 9

The Management of Manufacturing Trade-Offs

Introduction

This chapter discusses the major findings of this research. It compares the data analysis with the literature and the impressions and beliefs of the investigator. Given the explanatory nature of this research, the findings are presented as a series of propositions. These propositions may be formally tested (for example as hypotheses in surveys) or lead to further questions to be addressed in subsequent studies. These questions will be discussed in the next chapter.

This chapter aims to answer the research questions in Chapter 4. Those questions concerned (1) the relationship between trade-offs and production capabilities, (2) the nature of trade-offs, (3) the role of flexibility in the management of trade-offs and (4) the relationship between flexibility capabilities and resources in the context of trade-offs. In addition, the research findings may address other aspects of trade-offs that did not appear before the data collection but which emerged from the subsequent analysis of the cases.

Chapter 9 is organised as following. Section 9.1 discusses the concept and structure of trade-offs. This is called their background. Section 9.2 covers the nature of trade-offs Section 9.3 discusses the trade-offs sources. Section 9.4 is about the effects of trade-offs in manufacturing and strategy. Section 9.5 discusses the strategies to manage trade-offs. These are the elements of the framework of trade-offs discussed at the end of the Chapter (see Figure 9-1). Section 9.6 covers the role of flexibility in trade-offs management. Section 9.7 has the chapter conclusions and reviews that framework.

As discussed in Chapter 5, this research aims to explore the relationships between trade-offs, capabilities and flexibility to build a theory of manufacturing trade-offs that may be tested in subsequent studies. Research results are presented as a series of propositions relating to different elements of a framework (Figure 9-1). Each proposition is described along its relating data, literature and, where applied, examples and illustration.

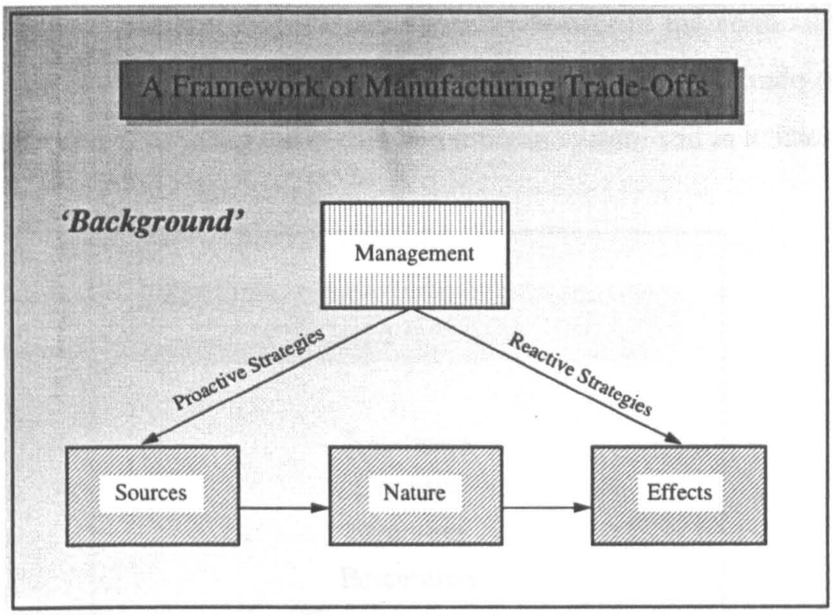

Figure 9-1: Framework of manufacturing trade-offs

9.1 The Concept and Structure of Trade-offs: Background

The present section discusses the major findings on the concept and structure of trade-offs. This is called the trade-offs background. It concerns the ways that people seemed to acknowledge and visualise trade-offs in the context of the case companies.

The trade-offs background has five major aspects. The first concerns whether trade-offs exist of not. This is the most important aspect of the trade-offs debate in the literature so far. Some recent surveys suggested that trade-offs exist (Filippini, Forza and Vinelli, 1995; Schroeder et al., 1996). Mapes' (1996) survey suggested the opposite. The research findings corroborate the first view and suggest that the differences between these findings may be due to (1) a lack of understanding on the properties of trade-offs in the context of operations and (2) a failure of these studies to recognise the *contingent* nature of trade-offs. Furthermore, following propositions in this chapter suggest that on focusing on this debate the literature fails to discuss some key issues on trade-offs that may be more relevant and elucidating.

The second aspect concerns the concept of trade-offs as proposed by managers of the case companies. The third aspect discusses the structure of trade-offs. This is about the major elements that seemed to characterise trade-offs in the context of the case companies. The final aspects concern the way people may perceive trade-offs and the differences between visualising trade-offs in a process system and in a batch system.

Trade-offs Background

Existence
Concept
Structure
Perception
Type of System

Figure 9-2: Aspects of the background of trade-offs

P1 Manufacturing trade-offs exist.

All the cases acknowledged the existence of some, or most, of the 10 trade-offs investigated. Most managers interviewed believed trade-offs (1) characterised their systems, (2) had different importance levels and (3) could be dealt with accordingly.

The idea that trade-offs do exist with varying levels of performance agrees with Skinner (1992), New (1992), Slack (1991) and Filippini, Forza and Vinelli (1995). It is opposed to studies such as Schonberger (1986), Collins and Schmenner (1993) and Mapes (1996) proposing that they do not exist since all MSDs are positively related.

However, while this literature has been debating whether trade-offs exist or not, the research findings suggest that it may be more important focusing on why and how trade-offs are relevant to MS. That trade-offs existed in the case companies was rarely disputed during the investigation. As one manager said, 'two objectives will always conflict at some level of performance'. Instead, the debate usually focused on whether one or another trade-off was *important* to MS and management.

Different managers and operators in the same company had sometimes different views on the same trade-off. The way people saw trade-offs seemed to depend on aspects such as their roles, values and knowledge of the organisation. The views of M1, M2 and M3 in Case B on how to improve trade-offs with quality are a major example. M2 - the Quality Manager - suggested that dealing with those trade-offs required increasing the role of a 'quality department' at the expense of multi-skilled jobs: "*If you try to do many things maybe you don't do anything as perhaps you ought to.*" M1 and M3 had an opposite view. They suggested that dealing with those trade-offs required increasing even more the role of integration, teams and multi-skilled jobs: "*By putting a CIM system enabled us to track our quality (on-time) and it made the trade-off between quality and speed weaker*" (M1).

P2 Manufacturing trade-offs are seen as compromises between MSDs.

Most managers viewed trade-offs as in this proposition. Different MSDs may have different types of relationship - independent, positive, negative; negative relationships are called trade-offs. For example, M1 in Case D defined QS and CS as following: "*... we can either make it faster or make it better, but not faster and better at the same time*" and "*... the faster we make it, the more expensive it is.*" This proposition compares with Skinner (1969) and other studies in MS. This concept is now almost canonical and is assumed throughout this research.

As seen on Chapter 8, other views were M1's and M2's in Case D and M2's in Case C. M2 in Case D suggested that trade-offs exist but do not impede achieving the level of performance required by the market. M2 in Case C suggested that trade-offs were conflicts between different areas. M1 in Case D suggested they were the result of the impact of external changes into the system's structure.

P3 The structure of trade-offs can be visualised as base, pivot and function.

Advancements in the knowledge of trade-offs have been improving the understanding of their nature, elements and effects on operations systems. One aspect of this knowledge is the definition of models of trade-offs. So far, OM studies presented two major models of manufacturing trade-offs, as illustrated in Figure 9-3.

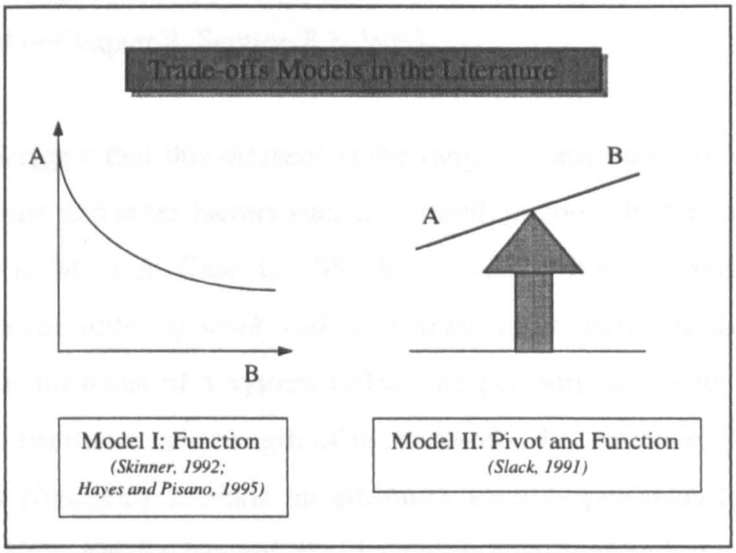

Figure 9-3: Trade-offs models in the OM literature

Some studies pictured trade-offs as a function of two variables (A and B). This function may be plotted in a XY graph (Model I). It indicates the expected performance of one variable at any level of performance of the other variable. This is in Skinner (1992) and Hayes and Pisano (1995). Model II was suggested by Slack (1991). It defines a new element besides the 'function': the pivot of the trade-off. The idea of the pivot suggests that trade-offs are dynamic, in opposition to the static view in Model I.

Slack et al. (1995) proposed that 'raising' the pivot should increase the level of the trade-off function. Hayes and Pisano (1995) corroborated this idea of improving trade-offs (by plotting 'improved' curves in the XY model). Slack et al. (1995), in spite of identifying the pivot, did not define which elements of an operations system constitute this, apart from the idea of 'technical and attitudinal constraints' (p. 871).

Given this context, this research aimed to define (1) what is the pivot in practice and (2) what does 'raising' the pivot mean. A proposition defined in Chapter 4, based on the literature review, suggested that *production capabilities* were the pivots. However, this idea was tested in the case studies and did not appear entirely appropriate. First, the role of capabilities in trade-offs is similar to the role of resources. Second, and most important, the cases suggested there is another element in between the development of capabilities and resources and the improvement of trade-offs. This has been discussed in Chapter 8, Section 8.3, WP3.

The findings suggest that this element is the range of 'attributes' of a system. These include flexibility and other factors such as reliability, co-ordination and productivity. One example is M1's in Case C: "*We have been trying to improve the process reliability... to (be able to) work with advanced technologies, tools, materials and methods.*" The attributes of a system reflect the performance of its capabilities and resources and determine the strength of its trade-offs. For instance, the trade-off cost versus quality (function) depends on attributes such as productivity and flexibility (pivot). This pivot can be 'raised' by improving resources and capabilities such as process technology and labour skills (which may be called the base of the trade-off). Thus, it seems more appropriate considering *production attributes* the trade-offs pivots while resources and capabilities are the bases of trade-offs. A new trade-off model is then proposed with three elements: base, pivot and function (see Figure 9-4). The ideas of attributes, capabilities and resources are further discussed in Section 9.3.

For example, if there is a trade-off between quality and cost (variables), its function will measure the correlation between quality and cost performance (which is obviously negative in this case). The shape of this function depends on a range of system's attributes (the pivot of the trade-off). For example, the process *reliability* determines the number of defective parts in a batch; the machines *flexibility* determines the cost of scrap incurred in machine set-ups. Finally, these attributes depend on the range and nature of the resources (such as machines and skills) and capabilities (such as set-ups and process abilities) available in the system. The dynamics of this model are following discussed.

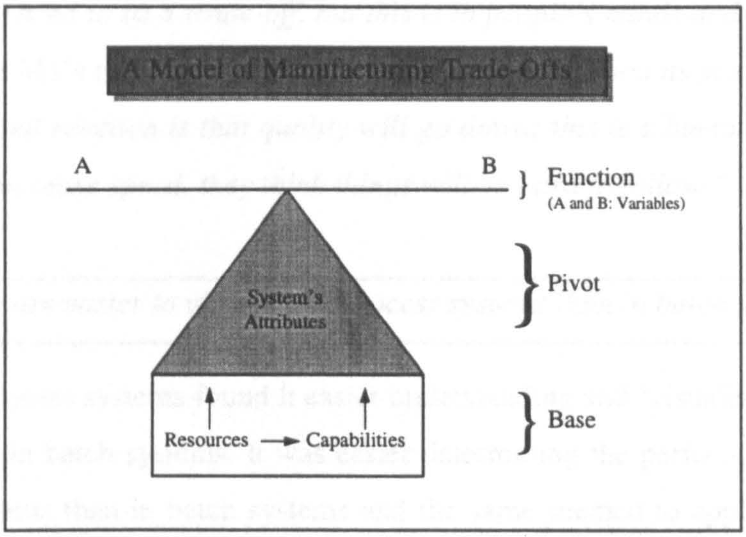

Figure 9-4: A model of manufacturing trade-offs

P4 Some trade-offs are seen by managers as existing more in people's perceptions than in reality.

A distinction such as between 'real' and 'perceived' trade-offs has neither been found in the literature nor anticipated in the research framework. However, this issue appeared frequently along the investigation. There is a thin line between the ideas of 'real' and 'perceived' trade-offs. One may suggest that all trade-offs are real but have different levels of importance or even that their importance depends on how they are perceived by individuals in the organisation.

The cases suggested that operations managers may divide trade-offs into 'real' and 'people's perception'. Depending on how they see trade-offs will lead to different approaches in their management. The management of 'real' trade-offs - the major focus of this research - may rely on strategies as on Section 9.5. When managers saw trade-offs as people's perception (as in cases B, D and E) they tended to focus on changing this perception (instead of changing the trade-off). Changing perceptions might rely on measures such as training or new performance measurement systems focused on consolidated variables or teams' performances.

Examples of seeing trade-offs as people's perception are M1's in Case D: *"I don't think they (QC) need to be a trade-off, but this is in people's minds and this is difficult to change"* and M1's in Case B: *"You actually find that, as soon as you say 'speed' to people, the actual reaction is that quality will go down; this is a human element, they don't want to increase speed, they think things will be hard to follow."*

P5 Trade-offs are easier to visualise in process systems than in batch systems.

Managers in process systems found it easier understanding and 'visualising' trade-offs than managers in batch systems. It was easier determining the performance of MSDs in process systems than in batch systems and the same seemed to apply to trade-offs between MSDs. The two process companies (Cases B and E) provided examples of simple, practical statements on trade-offs: "*By putting a CIM system enabled us to track our quality and it made the trade-off between quality and speed weaker.*" (M1, B) and "*With wine, the more you change the process, the more quality problems you have*" (M2, E). Such statements seemed often more difficult to make in the batch companies (specially Cases C and D).

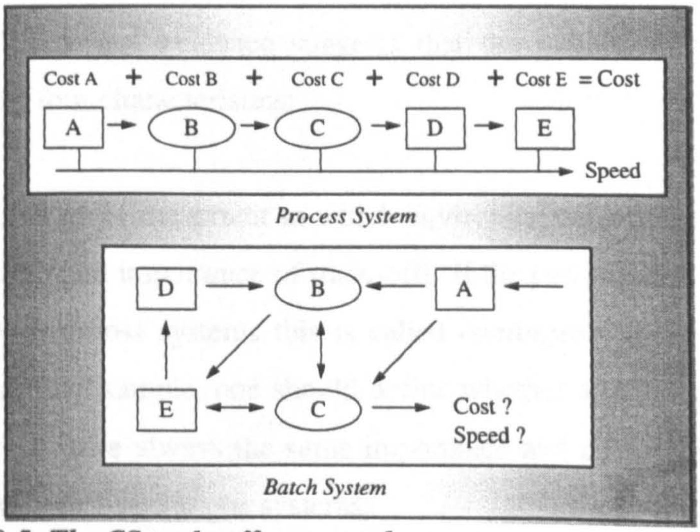

Figure 9-5: The CS trade-off - approach on process versus batch systems

Figure 9-5 suggests how a trade-off such as CS could be more easily acknowledged in process than in batch systems. This compares with leading OM studies (Monden, 1990; Drucker, 1990) suggesting that it may be easier to understand and control such 'linear' systems. This seems to apply to trade-offs management as well.

9.2 The Nature of Manufacturing Trade-offs

This section discusses the major findings on the nature of manufacturing trade-offs. Nature concerns the major characteristics of trade-offs in an operations context. This is the first element of the framework.

As has been suggested earlier, one of the major problems with the literature on trade-offs so far is the lack of understanding on their nature in an operations context. Major studies have been focusing on a debate on whether trade-offs exist or not. Few studies (if any) investigated aspects such as why different trade-offs seem to characterise different companies; whether they are dynamic; whether one can improve or eliminate trade-offs and whether different trade-offs should be related or not in that context.

However, this investigation suggests that these should be major aspects of a study on trade-offs. If one needs to understand the nature of trade-offs, a number of distinctions are necessary. The cases' evidence suggests that the nature of trade-offs may be defined by at least four characteristics:

1. **Adaptability**: This is the extent in which environmental variables may influence the performance and importance of trade-offs. If the performance or importance of a trade-off vary across systems this is called *contingent* otherwise this is called *deterministic*. For example, one should define whether a trade-off such as quality versus cost will have always the same importance and performance or these will vary across different operations systems;
2. **Changeability**: This is the tendency of trade-offs to change or have changed their performance or importance levels in a system. If a trade-off may change or be

changed it is called *dynamic* otherwise it is called *static*. For example, one should define whether a trade-offs such as speed versus variety will have always the same importance and performance in a system or these could change in time;

3. **Manageability**: Following the changeability, this is the *extent* in which one may change the importance or performance of trade-offs. This is whether trade-offs can be eliminated or there is a limit to their improvement. For example, if one can change the performance of that SV trade-off, one should define whether it is possible to eliminate it or only to minimise its strength or importance;
4. **Interdependence**: This is the extent in which different trade-offs may be related in a system's context. Different trade-offs may have the same sources or effects in the system and may be dealt with by similar measures. For example, one should define whether different trade-offs in a system should have the same origins or effects or these should be different.

The nature of trade-offs is the first element of the trade-offs framework. It consists in these four aspects (Figure 9-6). The next propositions discuss each of these aspects.

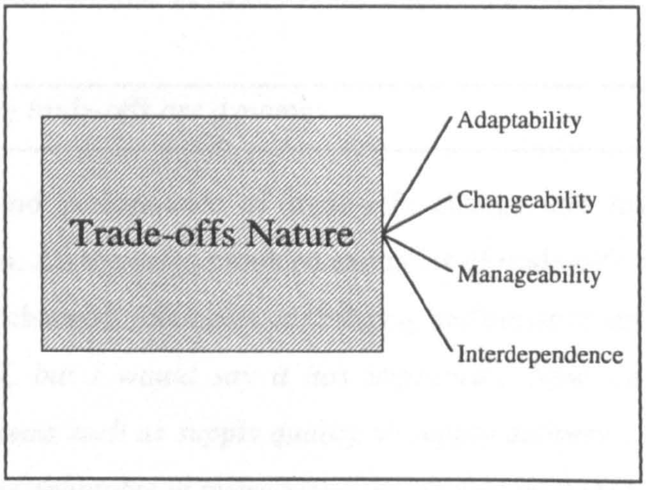

Figure 9-6: Aspects of the nature of trade-offs

P6 *Manufacturing trade-offs are contingent on environment variables.*

The importance (impact on strategy) and performance (strength) of trade-offs depend on a range of environment (external and internal) variables. These variables are here called performance and importance factors and will be discussed in following sections along with their corresponding data. Furthermore, as these variables change, the performance and importance of trade-offs should change as well (i.e. trade-offs are dynamic). This is discussed in the next proposition along with corresponding data.

The importance and performance and (in less extent) sources, effects and management of trade-offs all varied across the cases. Differences in trade-offs importance and performance levels were due to factors such as the firms' competitive strategies, market variables and range of capabilities and resources available.

The idea of trade-offs as contingent agrees with some OM studies. Filippini, Forza and Vinnely (1995) surveyed 42 metal-mechanical companies and found that different trade-offs always characterised between 24% and 42% of those. New (1992) presented six case studies that were characterised by 4 different 'key trade-offs' (QC, VC, SC, VS[1]) and even more varied key trade-offs 'issues'. The idea of contingent trade-offs disagrees with Ferdows and De Meyer (1990) 'Sand Cone Model'. They suggested that the relationships between MSDs are deterministic, for example "... cost can be reduced at no expense in terms of other capabilities..." (pg. 174).

P7 Manufacturing trade-offs are dynamic.

The importance and performance of trade-offs change and may be changed by management action. All the cases provided examples of trade-offs whose performance or importance had changed. Examples of changing performance are Case A's QS: "*QS is still a trade-off, but I would say it has improved... Now we are more readily adaptable to problems such as supply quality or supply delivery... the cell assemblies allow us to be more adaptable in overcoming these problems*" (M1) and Case E's QD: "*The introduction of enzymes and catalysts 15 years ago brought this relationship into a new stage...*" (M1). Examples of changing importance are Case B's SV: "*This is one of the problems here... if you want to be as flexible as possible, because there is a customer out there who wants variety, and you need to change from one product to*

[1] Where QC = quality capability vs. cost; VC = mix or design flexibility vs. cost; SC = lead time vs. cost; VS = mix or design flexibility vs. lead time.

another product... that can cause you time, so we had, say, 2 set-ups in a week and now we have 10" (M1) and Case C's QV "*This is very important... we have (now) 124 models and we know that it makes it difficult to guarantee their quality*" (M1).

As discussed in P6, the importance and performance of trade-offs depended on a range of environmental factors. Changing these factors changed the levels of performance and importance. The performance of Case A's QS improved after the assembly cells, increasing the system's speed and quality. The importance of Case C's QV increased after they changed their focus on MS from low to high products' variety.

This proposition agrees with studies such as Skinner (1992) and Hayes and Pisano (1994). Skinner (1992: 20) thus characterised trade-offs: "They are just as real as ever but they are alive and dynamic." Hayes and Pisano (1994: 81) presented the case of a company that minimised trade-offs by improving its capabilities and process technology. Earlier studies usually viewed trade-offs as deterministic, leading to ideas such as 'priorities setting' and 'focused factories'. Examples of such studies are Banks and Wheelright (1979), Miller (1983) and Skinner (1974: 115): "A factory cannot perform well in every yardstick".

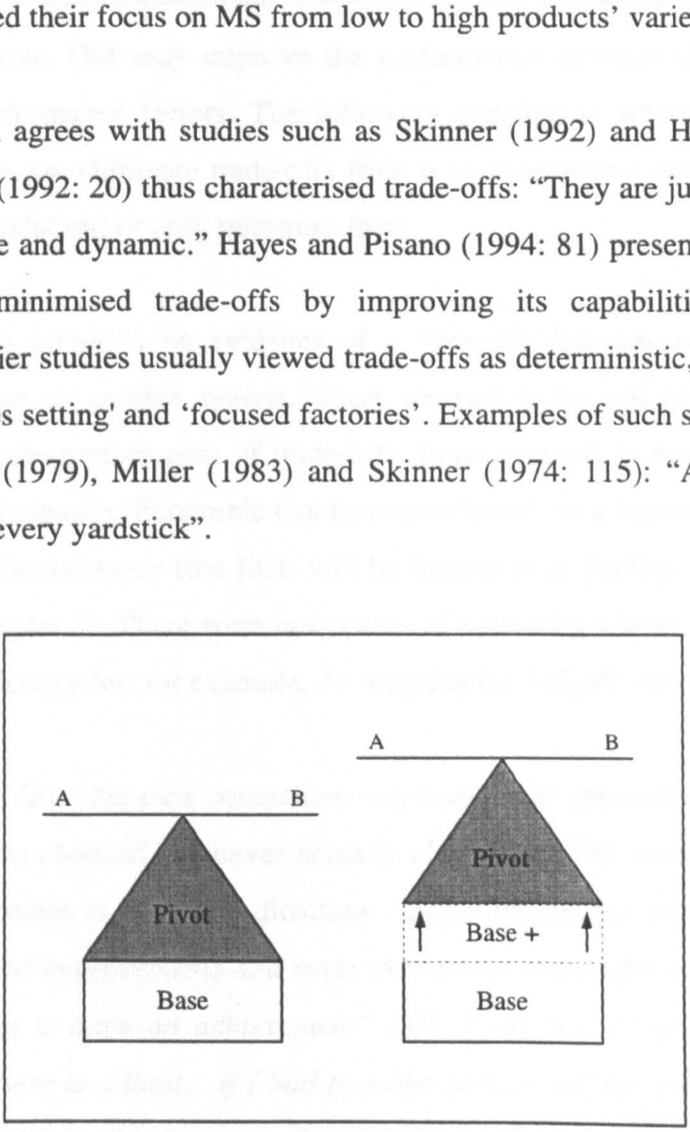

Figure 9-7: Dynamic trade-offs: performance improvement

Figure 9-7 shows that the performance of a trade-off improves after increasing its base and raising its pivot. It is important noting that the trade-off still exists after the improvement; only its function is in a higher level. This is one type of improvement - increasing both variables simultaneously. Section 9.5 will discuss other types.

As Hayes and Pisano (1994) pointed out, instead of selecting objectives (or MSDs) to improve, OM should select trade-offs to improve. Successful and continuous operations development focuses on OM practices instead of objectives.

P8 One can improve but not eliminate trade-offs.

As proposed above, OM may improve the performance of trade-offs by improving their related performance factors. The following question is whether by improving these factors one can eliminate trade-offs (that is to transform a negative correlation into positive correlation) or only minimise then.

The case studies provided no evidence of a trade-off that was *eliminated* due to managerial action or another reason. There seemed to be always a *limit* for the improvement of the performance of trade-offs. Improvements in performance factors could raise the trade-offs 'Economic Conformance Level' to a higher level *below*, but never *at*, 100% performance (the ECL will be discussed in Section 9.5 and has been presented in Chapter 3). There were only cases of trade-offs whose importance could become insignificant after, for example, de-focusing the MS off some MSD.

All the evidence from the case companies may lead to the speculation that trade-offs may change or be changed but never actually *eliminated*. The evidence provided by managers also points to the same direction: *"Some things you can get to the point where you can put improvements and make then less a trade-off but, to get then to be independent, that is quite an achievement"* (M1, Case A); *"You can improve the trade-offs, but there is a limit... if I had to make parts to all the cars in the world, it would be almost impossible in terms of costs with machines and tools... even if set-up costs were zero"* (M3, Case D).

Thus, it may be not always possible to OM to match the actual performance of trade-offs with their required levels. Hence strategies to *reduce the importance* of trade-offs may be sometimes used instead of or in combination with strategies to improve their performance. This will be discussed in Section 9.5.

P9 Different trade-offs may have common or similar sources, effects or management strategies.

The cases suggested that different trade-offs may have (1) similar sources and (2) effects on MS and (3) may be suitable to similar management strategies.

In Case B, trade-offs with quality were all affected similarly by the introduction of team-working and multi-skilled jobs. In Case E, the performance of both QV and SV depended on the cost and time of set-ups. In Case C, the performance of DV and DS improved after the introduction of new process technology, NC machines and cells. The networks of trade-offs, flexibility, resources and capabilities types presented in Chapter 7 (e.g. Case E's in Figure 9-8[2]) may well illustrate this idea.

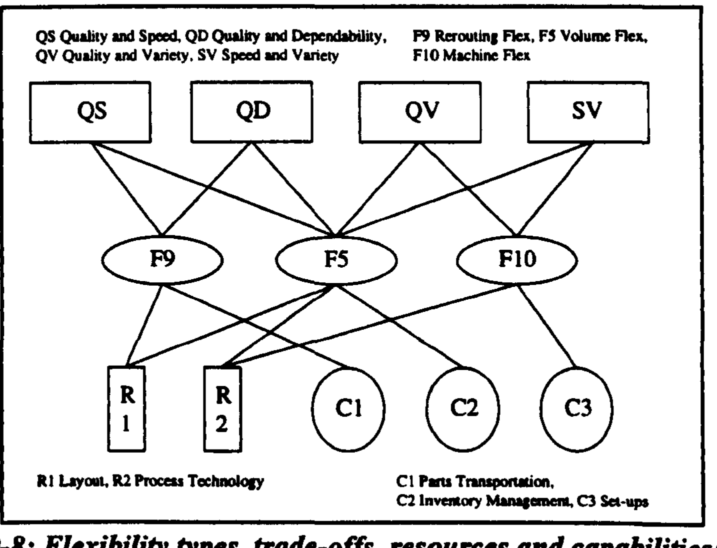

Figure 9-8: Flexibility types, trade-offs, resources and capabilities: Case E

New (1992) discussed the case of 'Food Coolers Inc.' This firm produced highly customised products that were not easily modularised. Hence two trade-offs with variety - VS and VC - were the most important there. Since those trade-offs had the

[2] Where Rn = resource types; Cn = capability types; Fn = flexibility types; trade-offs have the same abbreviations that have been used along these chapters.

same 'major' importance factor - competitive requirements for variety - their importance levels were similar.

9.3 The Sources of Manufacturing Trade-offs

The case companies suggested the existence of a number of different trade-offs. The performance of these trade-offs was obviously dependent on their context. This was always determined by a range of different factors (here called the sources of trade-offs) such as the systems' technologies, skills, managerial abilities and flexibility. A cross-case comparison of these data suggests that, in spite of these factors were usually different across cases, at least two generalisations may be attempted here.

First, the performance of trade-offs (the combined performance of their variables) always related to *internal* factors concerning the structure and infra-structure of the systems. Second, these factors could always be divided into *three groups*. Some factors concerned the range of resources of a system such as machines, skills and facilities. For example, the performance of QS in Case A depended on their workforce skills. A second group related to activities performed within the systems such as set-ups, management and production planning. For example, the strength of CV in Case C depended fundamentally on set-ups and inventory management. A final group concerned a range of system's attributes such as flexibility, reliability and capacity. For example, the performance of DV in Case D related to the range and response of production and machine flexibility.

This categorisation of these factors into three groups as well as their different roles in the base and pivot of trade-offs (following discussed) is entirely based on the cases' evidence. The literature discus in some extent the role of these groups in trade-offs but do not distinguish upon these categories or their roles on trade-offs.

This section covers these aspects of the sources of trade-offs (Figure 9-9). Proposition 10 concerns the idea of performance factors as internal to a system. Proposition 11 discusses the different types of performance factors that were evident and their role in the model of trade-offs that has been proposed in P3.

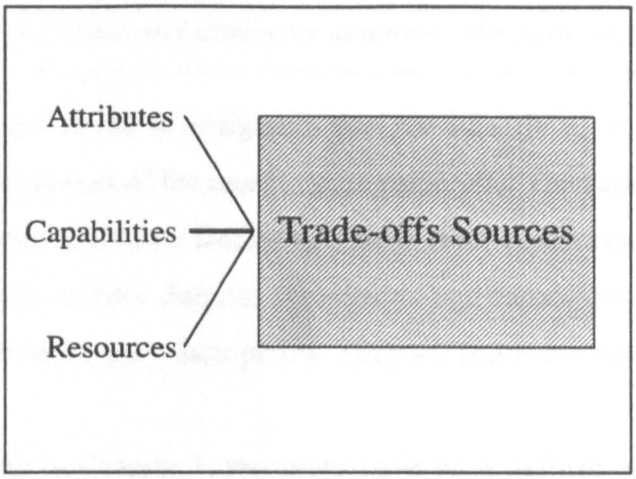

Figure 9-9: The sources of trade-offs

P10 The performance of trade-offs is determined by a range of internal factors.

As seen on Chapters 7 and 8, performance factors determine the strength of the relationship between the two variables of a trade-off. For example, abilities relating to products' development were a major determinant of the QS relationship in Case D. The relationship between two variables is their combined performance. It may be expressed as a function of one variable by the other (as discussed in P3).

In Case D, improving design abilities should improve the QS trade-off. It might be possible then (1) getting better quality at regular speed; (2) getting better speed at regular quality or even (3) getting simultaneously better speed and quality. In any case, the QS trade-off still exists after the improvement (i.e., quality remains negatively correlated with speed). Figure 9-10 (in P11) shows this idea.

This idea was suggested in recent studies on trade-offs. Hayes and Pisano (1994: 81) presented the case of 'Allegheny Ludlun' that minimised trade-offs by expanding its *capabilities*. Skinner (1992) suggested that technology (*resources*) is a major factor behind improving trade-offs. Slack et al. (1995: 871) described the role of *technical and attitudinal constraints* in raising the pivot. These studies used different terms to express the idea of performance factors. Thus the next proposition defines the elements that may be the performance factors.

P11 Resources, capabilities and attributes determine the performance of trade-offs.

One of the key issues of the investigation was the identification of the factors that determined the performance of the cases' major trade-offs. The summary of these data (in Table 9-1) suggests that these factors may be in three types: resources, capabilities and attributes. As will be later discussed, resources and capabilities were the bases of trade-offs, while attributes were their pivots. They are following discussed:

Resources - As seen in Chapter 1, resources have been defined as "... the stocks of available factors that are owned or controlled by the firm." (Amit and Schoemaker, 1993: 35). Resources are the technologies, methodologies and skills available to the firm. Each resource has a range of attributes (the same as potential performance) in areas such as a capacity, flexibility and reliability. Translating these attributes into actual performance requires their integration with other resources and capabilities. The data suggests that resources may be divided in four types: (1) operations technologies; (2) operations methodologies; (3) people's skills and (4) technologies and methodologies in related areas such as design, supply and logistics.

Capabilities - Capabilities have been defined as the processes, activities or functions performed within a system (Chandler and Hanks, 1994; Grant, 1991). They, as resources, also have a range of attributes whose translation into actual performance depends on their integration with other resources and capabilities. For instance, the capability 'making set-ups' may have attributes in reliability (how correct the set-ups are) and flexibility (time to cope with a number of related uncertainties). The cases' evidence suggests that capabilities may be in four types: (1) OM abilities; (2) shop-floor abilities; (3) system's development and (4) management of related areas.

Attributes: Attributes may be defined as the performance properties of resources, capabilities or entire systems. They measure an operations' 'internal performance' and may refer to any level of a system. Distinguishing upon 'internal' and 'external' performance measures is essential because they have distinct roles in trade-offs. Internal measures (attributes) are the trade-offs pivots. External measures (objectives or MSDs) are their variables. This investigation has focused on flexibility among the attributes suggested in the cases. Other types of attributes are reliability, co-ordination, process capacity and cost productivity.

Table 9-1 categorises the performance factors suggested in the case studies along with their related trade-offs.

Performance Factors	Related Cases	Related Trade-offs
• **Resources**		
Operations technologies: automatic sensors, NC machines, process technologies, process instrumentation.	B, C, D, E	QS, CV, DV, DS, QC, QD, QV, SV
Operations methodologies: layout, manufacturing cells, SPC.	A, B, C, E	QS, DV, DS, QD
People's (workforce and management) skills	A, B, C, E	QS, QC, QD, Others
Related areas' technologies and methodologies: CAD system.	A	QD
• **Capabilities**		
Operations management abilities: inventory management, production management, production planning and control, production scheduling, capacity management.	B, C, D, E	CV, QD, CS, CV, Others
Shop-floor abilities: operational abilities, line and machine set-ups, quality control.	A, B, C, D, E	CV, DV, DS, QS, QV, SV, QC, QD, Others
System's development: workforce training.	B, C	QS, DV, DS
Management of related areas: forecasting, product development, sales mgt., supply management, logistics.	A, C, D, E	QS, QV, CS, QD, Others
• **Attributes**		
Reliability: supply and process.	A, B, C, E	QC, QS, Others
Co-ordination	A, C, D, E	QC, QD, Others
Process capacity	A	Others
Flexibility: product, programming, process, labour, mix, delivery, production, machine, volume and rerouting.	A, B, C, D, E	ALL

Table 9-1: Performance factors - categories and related cases

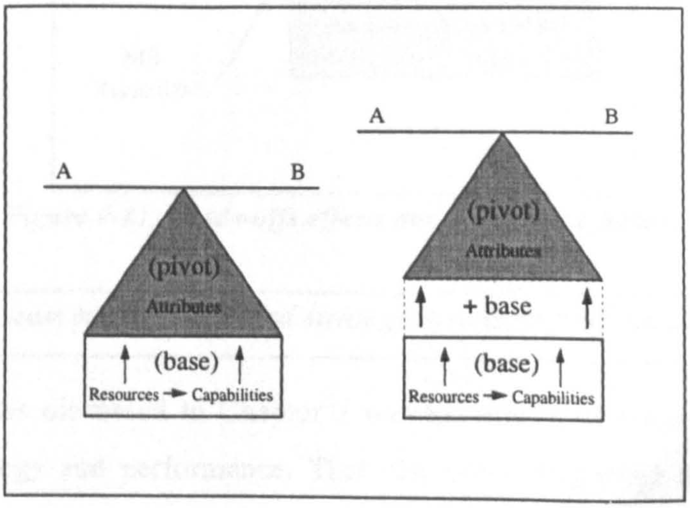

Figure 9-10: The role of resources, capabilities and attributes in trade-offs

Figure 9-10 illustrates the role of resources, capabilities and attributes in trade-offs as suggested in the case studies. The rationale for the allocation of resources and capabilities in the base and of attributes in the pivot of trade-offs is in P3, Section 9.1. This is further discussed in Section 9.5.

9.4 The Effects of Trade-Offs on Manufacturing Strategy

The trade-offs investigated in the case companies had a series of effects on MS and management. These effects were usually related and seemed to develop from the very concept of trade-offs. They were proportional to the importance of trade-offs in those systems. This importance depends on a range of marketing and strategic variables.

Section 9.4 discusses the effects and the importance of trade-offs in MS. It concerns two aspects: (1) what were the major effects of trade-offs in the cases (P12) and (2) which factors determined the importance of major trade-offs in that context (P13). This is the third element of the trade-offs framework (see Figure 9-11).

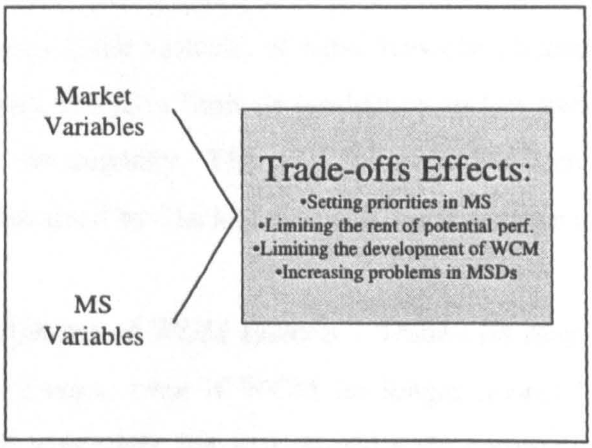

Figure 9-11: Trade-offs effects and importance factors

P12 Trade-offs seem to affect OM and strategy in at least four distinct ways.

One of the aspects discussed in Chapter 7 was the effects of trade-offs on the case companies' strategy and performance. That discussion suggested that these effects were often similar. Trade-offs seemed to affect the companies in four major ways:

Forcing the setting of priorities in MS and performance - If two MSDs are incompatible, OM has to set one as priority in decision-making, strategy formulation and performance goals setting. One example is M1's in Case B: *"My approach is what I have as my 'priorities of life'... I put health and safety number one and then I put quality, yield, then I put speed..."* This was a major assumption in earlier MS studies (Skinner, 1969; Banks and Wheelright, 1979) and led to the idea of focused factories (Skinner, 1974). This was challenged in early WCM studies (Schonberger, 1986; Collins and Schmenner, 1993), albeit with little empirical evidence.

Limiting the rent of the system's potential performance - Trade-offs may often explain the gaps between a system's potential and actual performance. At units' level, there is often a compromise between different performance objectives. For example, a machine may turn 100 parts/hour with no set-ups or 80 parts/hour with 5 set-ups. Such trade-offs may get even more significant at system's level (combining different resources and capabilities). For example, a machine may turn 100 parts/hour with no set-ups and a skilled operator or 90 parts/hour with still no set-ups but a non-skilled operator. It is not be possible in this situation renting both the full capacity and flexibility of the machine since they are incompatible. Case E had both the flexibility and demand to produce more varieties of wine. However, because of the QV trade-off (set-ups harm quality), it had to limit its production to few varieties corresponding to less than 80% of its capacity. The idea of gaps between potential and actual performance was discussed by Slack (1994) and Verdermerwe and Gilbert (1991).

Limiting the development of WCM systems - Trade-offs may hinder OM's attempts to develop WCM systems, even if WCM no longer means 'total performance', as Schonberger (1986) suggested, but just 'world-wide competitiveness'. As discussed above, the performance of resources and capabilities gets more difficult to predict and control as they combine with other resources and capabilities. This may explain the difficulties in integrating new technologies such as Flexible Manufacturing Systems with old systems (Upton, 1995). If the system's impact of new resources and capabilities is below expectations because of such trade-offs, developing WCM systems may take longer than expected. Case A had difficulties to reach WCM levels simultaneously in areas such as variety and speed: "*Providing increasing variety without being able to reduce the output rate is certainly a problem today*" (M1).

Increasing problems in the performance of MSDs - If there is a trade-off between, for example, speed and cost, failures in either speed or cost may harm the performance of both dimensions. For example, problems in speed might be caused by either long set-ups (a 'speed' problem) or by disruptions due to using cheaper but unreliable parts (to reduce cost). M1 in Case E suggested that the chronicly low speeds of labelling machines lead often to quality problems as well: "*If we increase its (a machine's) speed, its performance drops and many labels are stuck in wrong positions.*".

Table 9-2 summarises the major effects of trade-offs in the cases. These seemed to have different sizes and might be related (see Figure 9-12), depending on the nature of the companies' MS and trade-offs. The size and relationships between these effects could be further investigated in subsequent studies.

Effects **Cases**	**A**	**B**	**C**	**D**	**E**
Forcing the setting of priorities	X	X		X	X
Limiting the rent of potential performance	X	X	X		X
Limiting the development of WCM	X				
Increasing problems in MSDs	X		X	X	X

Table 9-2: Effects of trade-offs in the case companies

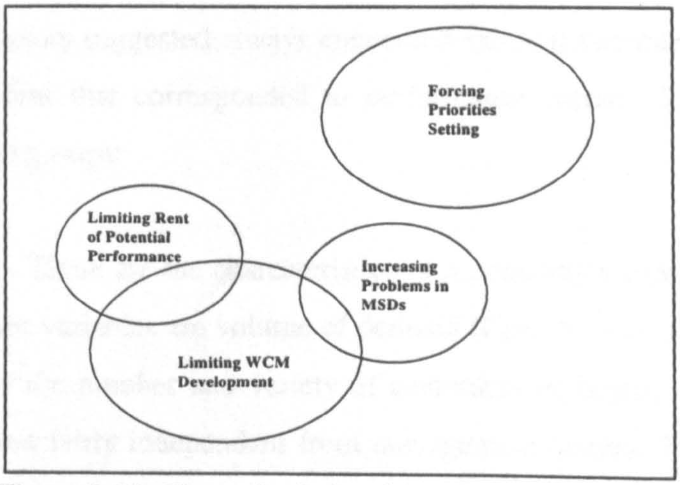

Figure 9-12: Size and relationships of trade-offs effects

P13 The importance of trade-offs is determined by a range of external factors.

As seen in Chapters 7 and 8, importance factors are the variables that determine the effects of trade-offs on MS. For example, the range of Case C's market segments was one of the determinants of QV's importance (Section 7.4.2). Since the importance factors of a trade-off are independent from its performance factors, its importance is independent from its performance. This was discussed in Chapter 8.

As discussed in P1, later studies focused on a debate on whether trade-offs exist or not. Examples of such studies are Skinner (1992), Schonberger (1986), Mapes (1996) and Schroeder et al. (1996). However, the research findings suggest that a focus on the effects of trade-offs on MS may be more appropriate and useful than disputes over their existence.

P14 Importance factors are market and strategy variables related to trade-offs.

As with performance factors (see P11), a key issue in data collection and analysis was the identification of the factors that determined the importance of trade-offs. One interesting finding of this research is that the importance of trade-offs in the cases was different from their performance. The investigation then aimed to identify which variables determined the importance of major trade-offs in the cases.

The importance factors suggested always concerned external variables, as opposed to the internal variables that corresponded to performance factors. These importance factors were in two groups:

Market variables - These are the characteristics of a company's competitive markets. Examples of market variables are volume of demand (Case A), customer expectations (all the cases) and the number and variety of customers or buying orders (Case E). Market variables are fairly independent from management actions. Firms may decide to get in or out markets, but they usually have to adapt to their circumstances;

Manufacturing strategy variables - These are the characteristics and choices relating to MS. Examples of MS variables are the MS priorities (Case A), the length of products life cycles (Case C) and the range of market segments where the firm operates (Case C). In opposition to market variables, these aspects depend on management choices.

Each company provided from 2 to 4 importance factors, fewer than the performance factors (from 10 to 19). This seems to develop from two factors: (1) importance factors had a broader scope than performance factors and (2) operations managers and operators were more familiar with the variables relating to performance factors than with such aspects as above. This problem was pointed out by Skinner (1969) and Hayes and Wheelright (1979a) and seems to be the case in those companies.

Table 9-3 summarises the importance factors from the cases with related trade-offs.

Importance Factors **Cases** **Trade-offs ↘**	**A**	**B**	**C**	**D**	**E**
Market Variables					
Volume of demand	QS, CS				
Customer expectations/requirements	QS, QC	ALL	QS	CS, DV	QV
Number and variety of orders					QD
Strength of market competitiveness		ALL	ALL		QS
Manufacturing Strategy Variables					
Manufacturing competitive priorities	QS, QC				
Range of market segments			QV		
Proximity to final customers					QD
Length of products life cycle			QC		
Products novelty (time since introduction)				QS	

Table 9-3: Importance factors, case companies and manufacturing trade-offs

Customers expectations and strength of competitiveness were the most common importance factors across the cases. The other factors appeared in one case only. Further investigation could determine the validity and generalisability of these variables as trade-offs importance factors.

Figure 9-13 shows the role of performance and importance factors in trade-offs. Differences between the performance and importance of trade-offs may explain the gaps between a system's required, potential and actual performance. The objective of trade-offs management is to even their importance and performance to close such performance gaps. This is now discussed further.

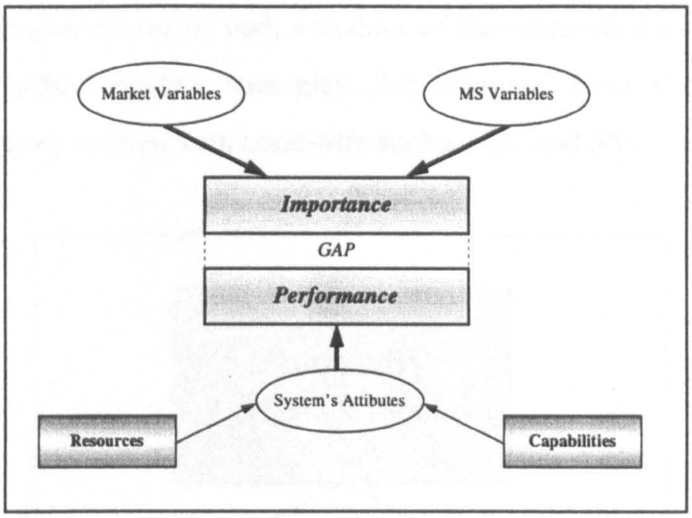

Figure 9-13: Trade-offs importance and performance factors

9.5 The Management of Manufacturing Trade-Offs

Trade-offs management is about the ways OM deal with manufacturing trade-offs. It aims to even the importance and performance of trade-offs. As discussed above, the performance of a trade-off (the combined performance of its variables) should match its importance (its effect in the MS). If the importance is bigger than the performance, the system probably lacks the resources or capabilities to match competitive requirements. If the performance is bigger than the importance, part of the system's potential is not being used. Such ideas are in the core of Slack's (1994) Importance-Performance Matrix.

One of the major focuses of the investigation was to define the ways that OM dealt with major trade-offs. The case data suggests they dealt with trade-offs by different strategies. These strategies seemed always related to two approaches (Figure 9-14). First, OM could focus on reducing the strength of trade-offs. This involved strategies to improve the performance of one or both variables of the trade-off through the development or integration of resources and capabilities into the system. These are called proactive strategies. For example, Case B developed a new process technology that was able to deliver (simultaneously) better quality and cost. Second, OM could focus on adapting the MS to the effects of trade-offs. This involved strategies to reduce the importance of one or both variables of the trade-off through changing the MS. These are called reactive strategies. For example, Case E reduced the MS importance of variety to cope with trade-offs such as QV and SV.

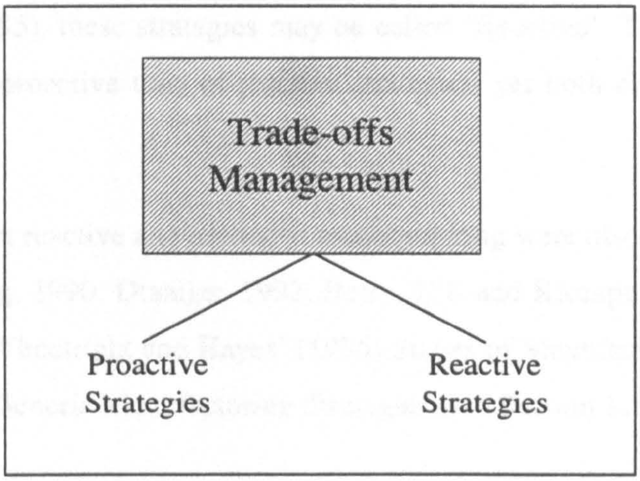

Figure 9-14: Trade-offs management strategies

These approaches are called trade-offs management strategies. This section discusses the types of trade-offs strategies suggested in the cases. Proposition 15 discusses those two major categories. Following propositions discuss the strategy types in each category and the role of resources, capabilities and flexibility in these strategies.

P15 Trade-offs management strategies may be divided into Proactive and Reactive.

The case companies seemed to deal with trade-offs through two major approaches. First, they could focus on *improving the performance* of a trade-off to match its importance. This is to focus on the sources of the trade-off - the resources and capabilities in its base and the attributes in its pivot. For example, M2 in Case A suggested that QD might be improved through better and more reliable set-ups: *"I am convinced you can get an improvement in quality and dependability if you have your system set up right at the first time... to make sure everything is right, and do not let it go until it is right."* Second, they could focus on *reducing the importance* of a trade-off to match its performance. This is to focus on its effects by changing the market and strategy variables that are its importance factors. For example, Case E reduced the role of variety in the MS (focusing on big volumes and few varieties) since trade-offs such as QV and SV could not be easily improved.

These approaches are opposite. The first one aims to improve the competitiveness of the system. Following Lindberg (1990), strategies under this approach may be called 'Proactive'. The second one aims to adapt the MS to the system's characteristics. Following Hill (1985), these strategies may be called 'Reactive'. The cases provided more examples of proactive than of reactive strategies, yet both characterised major trade-offs there.

Differences between reactive and proactive manufacturing were discussed in a number of studies (Lindberg, 1990; Draaijer, 1992; Berry, Hill and Klompmaker, 1995). This is the core idea in Wheelright and Hayes' (1985) Stages of Manufacturing Role and in Sweeney's (1991) Generic Manufacturing Strategies (see Section 1.1.2).

P16 Proactive strategies focus on the performance of trade-offs.

Proactive strategies aim to improve the performance of trade-offs. They should be applied whenever their cost is below the cost of corresponding reactive strategies. Proactive strategies focus on the performance factors of trade-offs (see Section 9.3). Improving these factors may either raise the trade-off pivot or change the shape of its function. In both cases, the change may affect the performance of one or both trade-off variables. Through branching these combinations of changes and effects and bounding with the evidence from the data, one may define at least three types of proactive strategies (see Table 9-4). These are following discussed.

Changes on \ Effect on	One variable	Both variables
Pivot	One side improves	Both sides improve
Function	Relationship improves	Relationship improves

Table 9-4: Proactive strategies: combinations of changes and effects

PS1 - One side improves: This strategy aims to raise a trade-off pivot to improve the performance of one variable at no expense of the other. The second variable may also improve in the period but this strategy focuses on the performance of the first only. Cases A, B, C and E provided examples of this strategy. Case C had been developing resources and capabilities such as NC machines, manufacturing cells, set-ups and inventory management to improve their ability to work with increasing variety at constant cost. Case A increased their speed at constant quality levels through better workforce skills, improving layout and increasing process, mix, labour, product and process flexibility. This strategy is appropriate when the performance of one variable only is below requirements and thus it is not necessary spending time and resources to improve both variables simultaneously.

PS2* - *Both sides improve: This strategy aims to raise a trade-off pivot to improve the performance of both variables simultaneously. It relies on developing resources and capabilities that may have a positive impact on both variables despite the nature of their relationship. Cases A, C and D provided examples of this strategy. Case C improved their production planning and supply to improve the performances of both quality and variety: "*Supply materials must be delivered with high quality and variety*" (M1). Case D combined a reactive strategy to deal with QS and CS (following discussed) with improving product development and line set-ups to improve cost, quality and speed simultaneously. Hence combining different strategies may be sometimes effective. This strategy is appropriate if the performances of both variables are below market requirements (and if focusing on both variables simultaneously is the most efficient approach). This strategy seems to be the best related to the idea of process re-engineering (Thomas and Davies, 1996; Peppard, 1996) as it focuses on many variables simultaneously.

***PS3* - *Relationship improves*:** This strategy focuses on the *relationship* between the variables instead of their *performance*. It aims to reduce the impact of one variable's performance on another, for example minimising the impact of one's failures on the other. This seemed to be the least frequent type of proactive strategies in the cases. Cases A and C provided examples of this strategy. In Case A, the implementation of assembly cells improved the process flexibility, minimising the impact of quality failures on speed: "*Now we are more readily adaptable to problems such as supply* *quality or supply delivery... the cell assemblies allow us to be more adaptable in overcoming these problems.*" (M1). Case C's M2 suggested that implementing new technologies improved the relationship between cost and quality. This strategy seems to be the most appropriate when the performances of both variables match market needs but their (incompatible) relationship unveils frequent problems to OM.

Figure 9-15 illustrates the three types of proactive strategies. Table 9-5 summarises the major cases' trade-offs relating to each type. Trade-offs with variety are the most frequent there because the investigation focused on improving trade-offs through increasing flexibility - the attribute best related to variety.

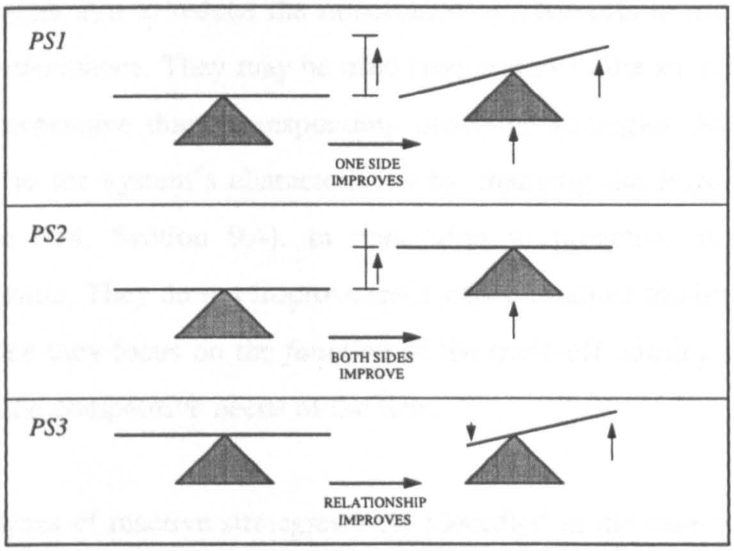

Figure 9-15: Types of proactive strategies

Proactive Strategies Cases / Major Trade-offs ↘	A	B	C	D	E
PS1 - One side improves	QS, QD, QV	CV, QV, SV	CV, SV, QV		QS, QD, QV, SV
PS2 - Both sides improve	QC, SV		QV	QS, CS	
PS3 - Relationship improves	QS, QD, QC		QC		

Table 9-5: Proactive strategies, case companies and major related trade-offs

An analysis of different strategies to deal with trade-offs was not found in the revised literature. Some studies proposed improving trade-offs by ways that are similar to these strategies. Ferdows and De Meyer (1990) proposed that some dimensions could be improved at no expense of others (as in the first type) if the Sand Cone Model (discussed in Chapters 3 and 8) was applied. Hayes and Pisano (1994: 81) presented the case of a company that improved trade-offs by strategies such as the first and second types: "One such endeavour developed capabilities that abled Allegheny to double the capacity of its melt shop without any physical expansion" and "This increase in capacity gave Allegheny the option of expanding its total output..., making more customised orders, or some combination of both." Skinner (1992: 20) suggested that "As technologies develop... the (trade-offs) relationships will change". This idea agrees with the third type.

P17 Reactive strategies focus on the importance of trade-offs.

Reactive strategies aim to reduce the importance of trade-offs to match their (*low or decreasing*) performance. They may be used (sometimes in the short term only) when they are less expensive than corresponding proactive strategies. Reactive strategies adapt the MS to the system's characteristics by changing the importance factors of trade-offs (see P14, Section 9.4). In opposition to proactive strategies, reactive strategies are static. They do not improve trade-offs but adjust the importance of their variables. Hence they focus on the *function* of the trade-off, aiming to find a balance that best suits the competitive needs of the firm.

At least four types of reactive strategies were identified in the case studies. These are called Reduction (RS1), Priorities Setting (RS2), Equilibrium (RS3) and Compensation (RS4) and are following described.

RS1 - Reduction: This strategy aims to reduce the competitive importance of one of the variables of the trade-off. *A trade-off loses importance when one of its variables loses importance.* Cases B, D and E provided examples of this strategy. Case B's M3 suggested that the short term solution for QS was to reduce the importance (performance requirements) of speed. Case E's M2 suggested dealing with QV and SV by reducing the strategic importance of variety (since the corresponding proactive strategy - improving quality and speed at no expense of variety - demanded big investments in process technology). This strategy is appropriate when it is possible to define a successful MS that does not depend on the variable of reduced importance.

RS2* - *Priorities Setting: This strategy aims to set one trade-off variable as competitive priority at the expense of the other. For example, if there is a trade-off quality versus cost, and if their performances are below requirements, the firm may decide to focus the MS on either quality or cost. Cases A, D and E provided examples of this strategy. Case A set quality as their competitive priority to cope with trade-offs such as QC, QS and QD: *"quality is our number one"*; *"we don't trade-off quality"* (M1); "... *(there is one point when) we have to stop because we will not sacrifice quality.*" (M2). Case D set quality as a priority over speed and dependability. This strategy follows Porter's (1985) theory of competitive advantage. It is valid if corresponding proactive strategies are more expensive.

RS3* - *Equilibrium: This strategy aims to maximise the combined performance of the trade-off variables. These 'combined' performance levels will correspond to the importance given to each variable along the MS. This strategy follows the 'Economic Conformance Level - ECL' model (see Chapter 3). The ECL model suggests that there is level of quality performance (in the QC trade-off) where the total costs of quality are minimal[3] (see Figure 9-16). This model may apply to other trade-offs such as dependability and cost (Slack, 1991). In spite of the importance of this model in the literature (Reitsperger and Daniel, 1991; Marcellus and Dada, 1991; Bowman, 1994), only Case B provided an example of this strategy. M2 suggested that they should balance (negotiate) the requirements for speed and quality to solve this trade-off: "*The solution is by negotiation and resolving conflicts.*" This strategy is valid if the firm may define a successful MS that matches these 'combined' performance levels.

RS4* - *Compensation: This strategy aims to identify an external variable to compensate for the effects of the trade-off. The idea is simple: if the benefits in 'A' (of increasing 'A' in an 'AB' trade-off) do not compensate for the reduction in 'B' then perhaps the benefits in 'A + C' will do. Cases A, C and E provided examples of this strategy. These examples applied always to cases of compensating reductions in cost productivity with an increase in another dimension. Case A's M2 suggested that

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[3] Assuming that their function is not linear.

increasing products' variety lead to *premium* prices that compensated a corresponding increase in assembly costs. Case C's M3 suggested that increasing sales volumes due to better quality paid for corresponding increasing manufacturing costs. Case E's M2 said that the DC trade-off was not important since customers would pay *premium* prices for products that were dispatched on time. This strategy is valid when there is a 'C' variable that may compensate for the decrease in 'B'.

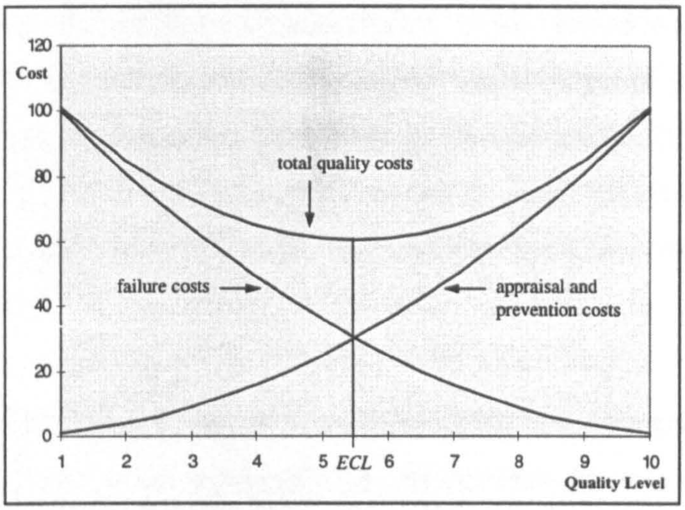

Figure 9-16: The Economic Conformance Level Model
Source: Reitsperger and Daniel, 1991

Figure 9-17 illustrates these four types of reactive strategies. Table 9-6 summarises the major cases' trade-offs relating to each type.

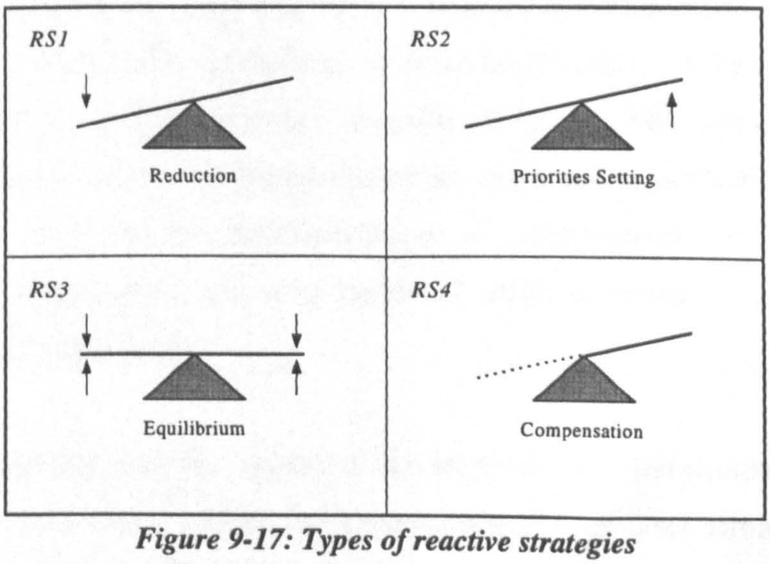

Figure 9-17: Types of reactive strategies

Reactive Strategies Cases Trade-offs ↘	A	B	C	D	E
RS1 - Reduction		QS, QV		CS	QS, QV
RS2 - Priorities Setting	QC, QD, SD			QS	QD
RS3 - Equilibrium		QS			
RS4 - Compensation	CV		QC		CD

Table 9-6: Reactive strategies, case companies and manufacturing trade-offs

Reduction and priorities setting strategies were the core of MS studies such as Skinner (1969), Miller (1981), Hayes and Wheelright (1979a) and Stobaugh and Telesio (1983). They were also the major idea in Porter (1985). Equilibrium strategies were discussed in studies such as Slack (1991) and Fry and Philipoom (1987) (concerning DC) and Reitsperger and Daniel (1991), Marcellus and Dada (1991) and Bowman (1994) (concerning QC). Compensation strategies were discussed in studies to evaluate the economic benefits of variety such as Yeh and Chu (1991) and Kekre and Srinivasan (1990).

As discussed in each topic, the use of proactive and reactive strategies is contingent on different contexts. The effectiveness of each strategy type depends on factors such as the nature of trade-offs, MS priorities and manufacturing performance. It is the role of OM to choose upon the strategy types that may be most appropriate in each context.

P18 Resources and capabilities determine the gaps in performance.

Sections 9.3 and 9.5 discussed the role of resources and capabilities in trade-offs. It has been proposed that they are the base of proactive strategies for the improvement of trade-offs. While reactive strategies concern choices in MS, proactive strategies concern the development and integration of resources and capabilities in the system. Development here is the implementation or improvement of resources and capabilities. Integration is the combination of different resources and capabilities towards specific objectives.

The data suggested that the impact of *development* and *integration* on trade-offs improvement was similar. Hence the investigation did not place strong emphasis on contrasting one from another. However, if one compares the case data with some ideas in the literature, it turns possible to speculate where there may be a distinction between these ideas. The hypothesis put forward is that the difference between development and integration is on their impact on gaps between a system's required, potential and actual performance.

Authors such as Gerwin (1993), Slack (1983) and Pyoun and Choi (1994) discussed the differences between a system's required, potential and actual performance. Albeit these studies focused on the measurement of flexibility, these performance types may refer to any MSD. As discussed in Chapter 2, required performance is the level of market needs, potential performance is the gross abilities of a system and actual performance is this system's effective achievements. Operations systems have usually gaps between their required, potential and actual performance levels. One may suggest that the role of OM is to close these gaps.

The gaps between performance types are related essentially to the idea of trade-offs. If a system's required, potential and actual performance were all the same, the importance (the same as required performance) and performance (the same as actual performance) of trade-offs would be the same. The role of resources and capabilities - closing the gaps between the importance and performance of trade-offs - is thus the same as closing the gaps between required, potential and actual performance levels.

The hypothesis put forward is that the role of **developing** resources and capabilities is to close the gaps between the *potential* and *required* performance and that the role of **integrating** resources and capabilities is to close the gaps between the *actual* and *potential* performance[4]. The explanation is as following. A system's *potential* performance depends on its range of resources and capabilities. One can not get more units in a day than his machines can possibly build. However, a system's *actual* performance depends on the combination of different capabilities and resources. The actual number of units that one gets depends on the combination of that machine with, for example, capabilities such as machine set-ups and maintenance.

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[4] This difference was not evident in the investigation because the trade-offs framework distinguished only between required and actual performance (the importance and performance of trade-offs). This difference emerges with the idea of the potential performance in between those two.

This hypothesis, illustrated in Figure 9-18, is based on ideas that emerged during the investigation and on their comparison with the literature. It could be tested in subsequent studies to improve the understanding of the role of resources and capabilities in OM.

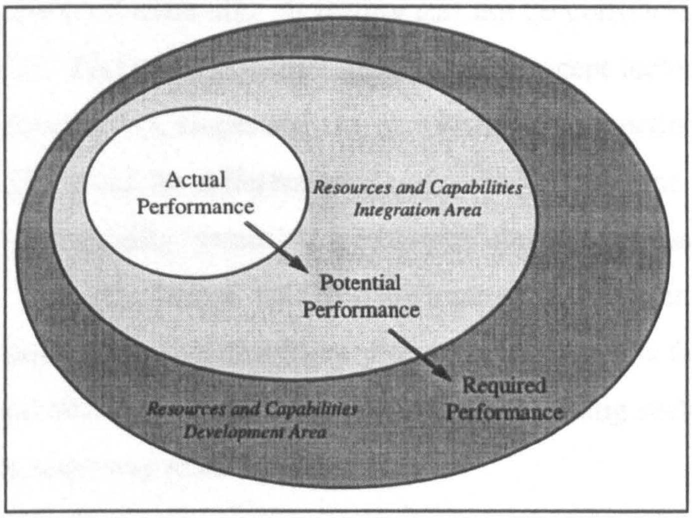

Figure 9-18: Resources, capabilities and performance gaps

9.6 The Role of Flexibility in the Management of Trade-offs

The relationship between flexibility and trade-offs has been one of the major focuses of this research. The literature on flexibility provided the main elements for the research framework along with the literature on trade-offs. To define this framework, it seemed necessary that its elements (such as the series of resources and capabilities, MS 'sub-dimensions', performance types and the idea of attributes versus objectives) were within the same OM scope. This has allowed, in practice, (1) establishing reliable relationships between those elements along the investigation and (2) drawing a data collection process that was both feasible and meaningful. Flexibility provided a reliable path to achieve this because it places these elements in a common context.

This research also aimed to investigate what is the role of flexibility in trade-offs management (see Chapter 4). Hence flexibility was part of both the means and the ends of this investigation. The research findings suggest that, in the context of trade-offs, flexibility is a process attribute and makes part of trade-offs pivots. This section discusses this finding and others on the relationship between flexibility and trade-offs.

P19 In the context of trade-offs, flexibility is a process attribute instead of MSD.

At least in the context of trade-offs, flexibility can not be considered as in the same level of other MSDs. Flexibility is a multidimensional concept including other MSDs in its formation (Slack, 1983; Gupta and Goyal, 1989). It is a function of cost, quality, dependability and/or speed for different levels of variety. Thus, one can not logically assess trade-offs of flexibility 'versus' (for example) cost. To increase flexibility *is* to decrease the cost of variety. Hence, on assessing trade-offs, the other MSDs should be compared with variety instead of flexibility. Fortunately, since this fact was perceived in the first case and confirmed in the others, the data concerning such trade-offs could be collected in the same way in all the cases.

The cases provided numerous examples of trade-offs of variety versus either cost, speed, dependability or quality. Flexibility was often in the pivot of such trade-offs (thus it was an attribute instead of dimension). The cases also provided examples of flexibility types in the pivot of trade-offs that did not include variety. Finally, major 'flexibility' resources (such as FMS, NC machines and team-working) and capabilities (such as set-ups and design) were commonly associated with the base of trade-offs. These were with or without flexibility in their pivot and with or without variety in the function. Figure 9-19 shows the role of these flexibility variables in trade-offs.

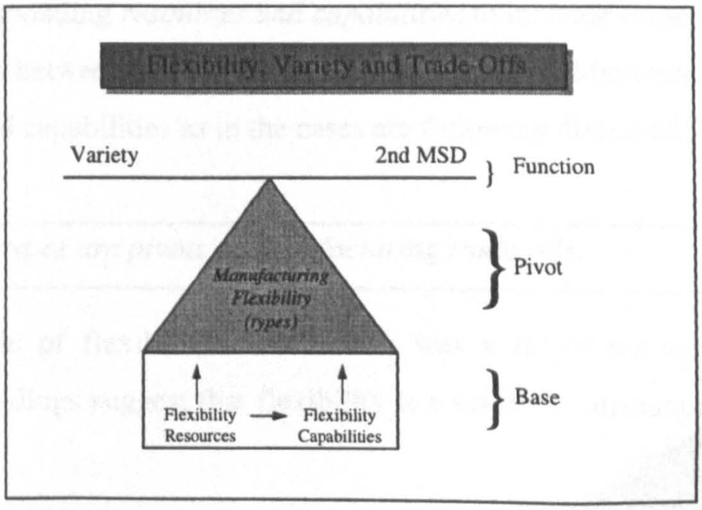

Figure 9-19: Trade-offs with variety and flexibility

The model in Figure 9-19 is not exhaustive. Flexibility may be in the pivot of trade-offs not involving variety. Trade-offs with variety may have other attributes in their pivot besides flexibility and other resources and capabilities in their base besides the ones usually associated with flexibility. Nevertheless, given the close relationship between variety and flexibility, this model seems to represent the most frequent situations involving these variables.

As seen on Chapter 3, Section 3.3, there is some confusion in the literature regarding the role of variety and flexibility in trade-offs. Some studies discussed trade-offs between flexibility and other variables (Gerwin, 1993; New, 1992; De Meyer et al., 1989). Other studies investigated trade-offs with variety (Upton, 1996; Mapes, 1996; Yeh and Chu, 1991; Kekre and Srinivasan, 1990; Nemetz and Fry, 1988). The research findings combine better with those later studies, specially the ones focusing on the impact *of flexibility in variety*. These include studies in scope economies such as Milgrom and Roberts (1990) and Goldhar and Jelinek (1990). Later studies seemed to acknowledge this problem. De Groote (1994) pointed out the need for distinguishing upon the ideas of flexibility and variety in OM. Schroeder et al. (1996) suggested that they had difficulties to measure flexibility as part of trade-offs.

The implications of P19 to OM are simple. First, managers have to focus on managing trade-offs between *variety* and cost, quality, speed and dependability. Second, they may look for appropriate *flexibility types* to improve those trade-offs. Third, they need to develop corresponding *resources and capabilities* to increase those flexibility types. The relationships between trade-offs and flexibility types and between flexibility types and resources and capabilities as in the cases are following discussed.

P20 Flexibility types are pivots of manufacturing trade-offs.

Defining the role of flexibility in trade-offs was a major research objective. As discussed, the findings suggest that flexibility is a system's attribute and is a pivot of trade-offs[5]. To refine this idea, it has been necessary to link between flexibility types and the major trade-offs in the cases. Not all major trade-offs seemed related to specific flexibility types. However, the variety and scope of flexibility types in the literature (see Chapter 2) suggests that many of such relationships should be expected.

The identification of flexibility types along the cases was in various forms. Sometimes they were identified by their concept (e.g. machine flexibility is the ability a machine has to perform various types of operations). Other times, they were identified by performance measures (e.g. machine flexibility is the number of operations it may perform within a certain amount of cost or time). Finally, they were at times identified by their related resources and/or capabilities (e.g. machine flexibility concerns machine set-ups). Using one or other form depended on factors such as the people involved (managers or operators) and the technical context of the company. Along with the variety and scope of flexibility types discussed above, these various forms of identification also helped to emphasise the role of flexibility in those trade-offs.

Among the eleven flexibility types used in the research, only expansion flexibility did not relate to any major trade-off in the cases. Flexibility types related always to proactive strategies to improve trade-offs (see Section 9.5). Improving flexibility types affected trade-offs as in the three types of proactive strategies: increasing one variable (e.g. improving product flexibility in Case A increased design speed at constant quality); increasing both variables (e.g. improving labour flexibility in Case A increased workers' autonomy and therefore their speed and quality) and increasing the relationship (e.g. improving process flexibility in Case C improved the relationship between quality and cost).

Few different flexibility types (maximum 5) related to trade-offs in each case. On the other hand, each type often related to many major trade-offs. Since the number of major trade-offs in each case was relatively narrow, it thus seems that improving flexibility types had usually a broad impact on trade-offs. This broad impact seemed

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[5] Besides flexibility, other attributes such as reliability and capacity may be in a pivot, while a pivot may consist of many attributes (see Section 9.4, Table 9-1). This section focuses on flexibility only.

more important than the effects of those flexibility types on specific MSDs. Table 9-7 illustrates the relationships between flexibility types and the major cases' trade-offs.

Type \ Case Trade-offs ↘	A	B	C	D	E
Product	QS, SV, QC		QV	QS, CS	
Mix	QS				
Delivery		CV			
Production		CV			
Volume			CV, SV		QS, QD, QV, SV
Expansion					
Process	QS, QD, SV	QS, SV	QC, QV		
Programming	QC, QD				
Rerouting					QS, QD
Machine		QS, SV, CV	CV, SV		QV, SV
Labour	QS, QD, QC, SV, QC		QV, SC		

Table 9-7: Flexibility types, case companies and major trade-offs

The idea that developing flexibility types may affect several performance measures together was suggested in some studies. Benjaafar, Talavage and Ramakrishnan (1995) suggested that flexibility might have a positive correlation with 'several measures of performance'. Benjaafar (1994) proposed that flexibility might relate to several elements of performance and usually has a positive impact on both the average and variance (consistency) of performance measures. Cox (1989) suggested that single types such as mix and volume flexibility might have a positive impact on different measures such as production lead times, set-up times, lot sizes and WIP inventory. These studies corroborate the idea that flexibility types may be the pivot of trade-offs, whilst suggesting that they may have a positive impact on various performance measures simultaneously.

P21 Flexibility resources and capabilities are bases of manufacturing trade-offs.

Section 9.3 discussed the role of resources and capabilities as bases of trade-offs. The present proposition brings that idea to the context of flexibility. If flexibility types are pivots of trade-offs and are improved by developing flexibility resources and capabilities, then flexibility resources and capabilities are bases of those trade-offs. This is in Figure 9-19 above. Table 9-8 shows the major examples of relationships between flexibility types, resources and capabilities in the cases.

Flexibility Type \ Case	A	B	C	D	E
Product	CAD, Design for Manuf'bility		Design Teams, Forecasting, Supply Mgt., CAD, CAM	CAD	
Mix	PPC, Assembly Cells, MRP II				
Delivery		Scheduling, Cells, Perf. Measurement			
Production		Cells, Set-ups, Perf. Measurement		NC Machines, Set-ups, TOC	
Volume			MRP, Inventory Management	MRP, TOC, CAM, Inventory Management	Process Technology, Layout, Inventory and Capacity Mgt.
Process	Assembly Cells, Labour Skills	Supply Mgt., New Materials	Process Technology, Training		
Programming	Labour Skills, Training				
Rerouting					Layout, Parts Transportation
Machine		Manuf. Cells, Set-ups	NC Machines, Set-ups	NC Machines, Set-ups, TOC	Process Technology, Set-ups
Labour	Training, Assembly Cells, Labour Skills		Training, Labour Skills		

Table 9-8: Flexibility types, case companies and flexibility resources and capabilities

These relationships are similar to those in the literature review in Chapter 2, Sections 2.2.2 (capabilities) and 2.3 (resources - technologies and methodologies).

Developing or integrating resources or capabilities usually increased the range and/or response of related flexibility types. As Table 9-8 shows, specific resources or capabilities could relate to more than one flexibility type and each flexibility type usually related to more than one type of resource or capability in the cases. Evidently, developing these resources and capabilities could also affect other system's attributes such as capacity, reliability and co-ordination, as discussed in Chapter 7.

9.7 Chapter Conclusions

Chapter 9 discussed the major research findings on the concept, nature and management of manufacturing trade-offs. Following the explanatory character of this study, these findings were presented as a series of research propositions on different aspects of trade-offs.

Each section of this chapter covered a different element of a general framework of manufacturing trade-offs. These discussions covered each element along with its major features and their relationship with other elements. This framework (Figure 9-20) summarises the major ideas in this chapter, aiming to extend the knowledge on manufacturing trade-offs and to provide a solid basis for subsequent studies.

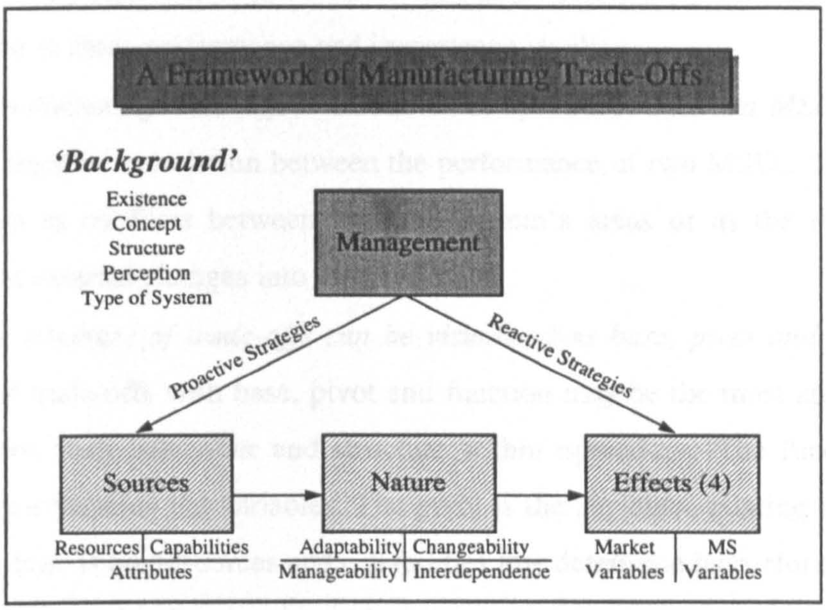

Figure 9-20: The framework of manufacturing trade-offs: overview

The *background* of the framework (Section 9.1) discussed the major ideas on the concept and structure of trade-offs. These aspects included whether trade-offs exist, their concept, elements in their structure, people's perception on trade-offs and how they may be visualised in different types of production systems. Section 9.2 covered the *nature* of trade-offs. This concerned the major characteristics of manufacturing trade-offs. The cases' evidence suggested that trade-offs are dynamic, contingent, manageable and interdependent. Section 9.3 discussed the *sources* of performance of trade-offs. Trade-offs performance factors are the resources, capabilities and attributes of a system. Section 9.4 covered the *effects* and the importance factors of trade-offs. These importance factors are the firms' market and MS variables. Section 9.5 discussed the *management* strategies do deal with trade-offs. These strategies were divided into Proactive and Reactive. Still on this aspect, Section 9.6 discussed the role of *flexibility* in the management of trade-offs.

The research findings were presented as a series of 21 propositions concerning these elements as following:

On the model and concept of manufacturing trade-offs (background):

- *P1 Manufacturing trade-offs exist.* Trade-offs characterise manufacturing systems and have varying levels of performance and importance. They should be dealt with according to these performance and importance levels;
- *P2 Manufacturing trade-offs are seen as compromises between MSDs.* A trade-off is a negative correlation between the performance of two MSDs. They may be also seen as conflicts between different system's areas or as the result of the impact of external changes into the system;
- *P3 The structure of trade-offs can be visualised as base, pivot and function.* A model of trade-offs with base, pivot and function may be the most appropriate to understand their behaviour and structure within operations. The function is the correlation between the variables. The pivot is the attributes relating to the trade-off. The base is the resources and capabilities that determine its performance;
- *P4 Some trade-offs are seen by managers as existing more in people's perceptions than in reality.* Managers may see trade-offs either as existent or as other people's perception. Depending on the way they see trade-offs they may focus either on changing trade-offs or on changing perceptions;
- *P5 Trade-offs are easier to visualise in process systems than in batch systems.* The simplicity of process systems in comparison to batch systems makes it easier to visualise the performance of individual MSDs and of trade-offs between MSDs in the former type that in the later.

On the nature of manufacturing trade-offs:

- *P6 Manufacturing trade-offs are contingent on environment variables.* The performance and importance of trade-offs depend on a range of internal and external variables;
- *P7 Manufacturing trade-offs are dynamic.* The performance and importance of trade-offs change in time and may be changed by managerial action;

- *P8 One can improve but not eliminate trade-offs.* Case data suggest that managers could improve the performance of trade-offs by changing their relating performance factors. However, this never seemed to lead to their elimination;
- *P9 Different trade-offs may have common or similar sources, effects or management strategies.* Different cases' trade-offs were often related. They might have the same sources (performance factors) or effects (importance factors). They might also be changed by similar management strategies.

On the sources of manufacturing trade-offs:

- *P10 The performance of trade-offs is determined by a range of internal factors.* There is a range of factors that determine the performance (strength) of trade-offs. These are internal and concern the structure and infra-structure of the system;
- *P11 Resources, capabilities and attributes determine the performance of trade-offs.* The factors that determine the strength of trade-offs in a system may be divided into three categories. These are resources (technologies, methodologies and skills), capabilities (abilities, activities and management) and attributes (a system's 'internal performance').

On the effects of trade-offs on manufacturing strategy:

- *P12 Trade-offs seem to affect OM and strategy in at least four distinct ways.* The major effects of trade-offs on the case companies were (a) forcing the setting of priorities in MS and performance, (b) limiting the rent of the system's potential performance, (c) limiting the development of WCM systems and (d) increasing problems in the performance of MSDs;
- *P13 The importance of trade-offs is determined by a range of external factors.* There is a range of factors that determine the importance (impact) of trade-offs. These are always external and concern the firm's competitive strategy;
- *P14 Importance factors are the market and strategy variables related to trade-offs.* The factors that determine the importance of trade-offs may be divided in two categories. These are market variables (such as volume of demand and customers'

expectations) and MS variables (such as MS competitive priorities and length of products' life cycle).

On the management of manufacturing trade-offs:

- *P15 Trade-offs management strategies may be divided into Proactive and Reactive*. The case companies would deal with trade-offs through two major approaches. The first, called Proactive, focuses on changing trade-offs. The second, called Reactive, focuses on adapting the MS to the effects of trade-offs;
- *P16 Proactive strategies focus on the performance of trade-offs*. Proactive strategies aim to improve the trade-offs performance. They may change a trade-off pivot or function and may affect the performance of one or both of its variables;
- *P17 Reactive strategies focus on the importance of trade-offs*. Reactive strategies aim to reduce the importance of trade-offs. They adapt the MS or the system's performance requirements to their nature and effects;
- *P18 Resources and capabilities determine the gaps in performance*. The role of developing and integrating resources and capabilities in a system is to close the gaps between its required, potential and actual performance. This is to even the performance and importance of trade-offs.

On the role of flexibility in the management of trade-offs:

- *P19 In the context of trade-offs, flexibility is a process attribute instead of MSD*. One should always assess trade-offs involving variety rather than flexibility. Flexibility is in the pivot rather than in the function of trade-offs;
- *P20 Flexibility types are pivots of manufacturing trade-offs*. The role of increasing flexibility types is to increase the performance of relating trade-offs. Increasing flexibility types have usually a broad impact in many trade-offs;
- *P21 Flexibility resources and capabilities are the bases of manufacturing trade-offs*. The major role of developing flexibility resources and capabilities is to increase the levels of flexibility types that may positively affect trade-offs.

Chapter 10 - Conclusion

Chapter 10
Conclusion

Introduction

This is the final chapter of this research. It reviews the whole investigation, aiming to highlight its major findings, the topics that could lead to further research and its implications for operations managers and researchers.

The major aim of this research was to extend the knowledge about manufacturing trade-offs. This consisted in finding out and explaining what may be their major elements, attributes and relationships in the context of manufacturing. The findings suggested that trade-offs may be characterised by four major elements: (1) sources, i.e. the resources and capabilities that determine their strength; (2) nature, i.e. their major characteristics in the context of operations; (3) effects, i.e. their impact on operations management and strategy and (4) management, i.e. the ways that operations managers may deal with trade-offs. This framework seemed a valid interpretation of the cases' data and thus formed the basis for further developments. The researcher believes that the research findings can undoubtedly clarify many aspects of trade-offs and thus accomplish that major objective. A simple comparison between the research findings in Chapter 9 and the research framework in Chapter 4 (based on the literature) may illustrate how far this thesis achieved its objectives.

The management of trade-offs concerns the *improvement of OM options*. One may analyse the major developments in the MS literature since 1969 by describing its approach towards OM options. Earlier studies focused on the *choice of options*. Focused factories are a major example of this approach. Following studies urged the *disregard of options*. World Class Manufacturers could achieve everything. The final school - of which this research is part - believes in the *improvement* rather than the choice or disregard of options. In other words, OM is no longer about '*how to make it cheaper*' or '*how to make it faster*' but simply '*how to make it*'. This has been the fundamental assumption of this study.

10.1 Major Research Findings

The contribution of this research can be illustrated by at least five topics:

- The progression from the descriptive analysis of trade-offs (still characterising most of the literature) to a more explanatory and, hopefully, elucidating stage;
- The development of a trade-offs model that may represent and explain trade-offs more usefully than the previous models in the literature;
- The distinction between the performance and the importance of trade-offs that may contribute to a better understanding of the sources and effects of trade-offs in practice. This distinction does not appear in the literature and seems to help to clarify many questions;
- The taxonomy of strategies to deal with trade-offs, summarising the approaches of the cases' OM for improving trade-offs or adapting the system to their effects;
- The findings on the role of flexibility in trade-offs and on the distinction between flexibility and variety. Again, this may help to clarify some questions about trade-offs and about flexibility in the context of MS. It may also be a useful contribution to the nature of 'objectives' in MS formulation.

The Progress from Descriptive to Explanatory Research of Trade-offs

The progress in the research of trade-offs from a descriptive to an explanatory stage is probably the most important formal contribution of this study.

As discussed in Chapter 5, Section 5.1.1, Meredith et al. (1989) suggested that typical OM studies progress across three stages of a cycle. *Descriptive* research acknowledges and reports facts and events. *Explanatory* research builds concepts and explains relationships between facts and events. *Testing* accepts or rejects propositions defined by explanatory research.

By focusing on the debate on whether trade-offs exist or not, most studies in trade-offs appear to be in the descriptive stage. These include early MS studies such as Skinner (1969) and Miller (1981), WCM studies such as Schonberger (1986) and Collins and Schmenner (1993) and surveys such as Mapes (1996) and Fillipini, Forza and Vinelli (1995). While all these studies may have an explanatory component, they are essentially descriptive as they aim to report the existence of trade-offs.

Later MS studies can be called explanatory as they aim to explain rather than report trade-offs. They focus on questions such as what is the nature of trade-offs and how does one deal with trade-offs. However, these studies (such as Skinner, 1992; Slack, 1991; New, 1992 and Hayes and Pisano, 1994) discuss a range of MS concepts and dedicate little space to trade-offs.

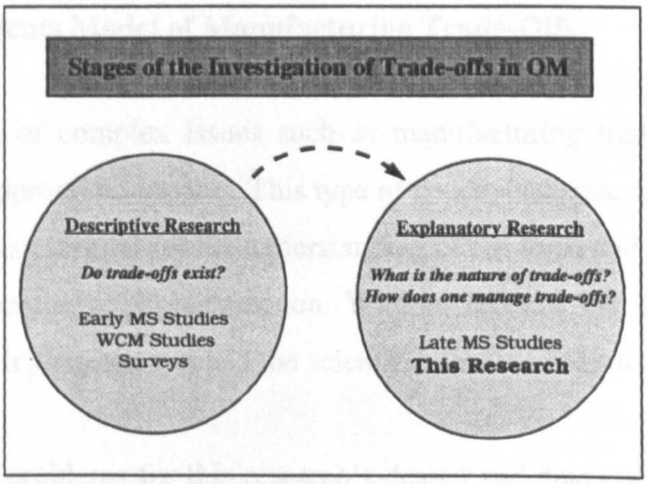

Figure 10-1: Stages of the investigation of trade-offs in OM

To the extent of this author's knowledge, this research is the first *explanatory* and *in-depth* study on manufacturing trade-offs that effectively investigates important issues such as their importance versus performance, the strategies to deal with them and major aspects of their nature. The progress from a descriptive to an explanatory stage in the study of trade-offs is a major contribution of this research. This is illustrated in Figure 10-1.

This advancement in the study of trade-offs may be important for the whole of OM. The author considers that the role of trade-offs in operations strategy formulation and improvement may be far greater than has been regarded in the literature. While formal studies on trade-offs have been focusing on their description, other OM areas may have been much more effective in providing this knowledge, by simply developing strategies to deal with major trade-offs. Strategies such as time-based competition, mass customisation and focused factories effectively consider the importance of trade-offs such as with speed, variety or cost and thus aim to provide adequate means to deal with them. The explanatory, in-depth investigation of trade-offs may thus (a) advance the knowledge about the nature and impact of these strategies, (b) provide a framework for their comparison and combination and (c) lead to more effective means of MS formulation and improvement.

The Three-Elements Model of Manufacturing Trade-Offs

The investigation of complex issues such as manufacturing trade-offs requires the development of appropriate models. This type of conceptual description, as defined by Meredith (1993), is essential for the understanding of the form and relationships of the elements that characterise a phenomenon. Without models, one can not understand basic ideas on such phenomenon and the scientific debate has little ground to develop.

One of the major problems for this research's design and data collection process was the lack of quality models of trade-offs in the literature upon which one could base further developments. Figure 10-2 presents the models from the literature. The ideas developed in the literature review in Chapter 3 were mostly based upon Skinner's (1992) 'Function' model. This model describes trade-offs as a function of two variables. Later on, the review of Slack's (1991) 'Pivot and Function' model formed the basis for the development of more complex work propositions in Chapter 6.

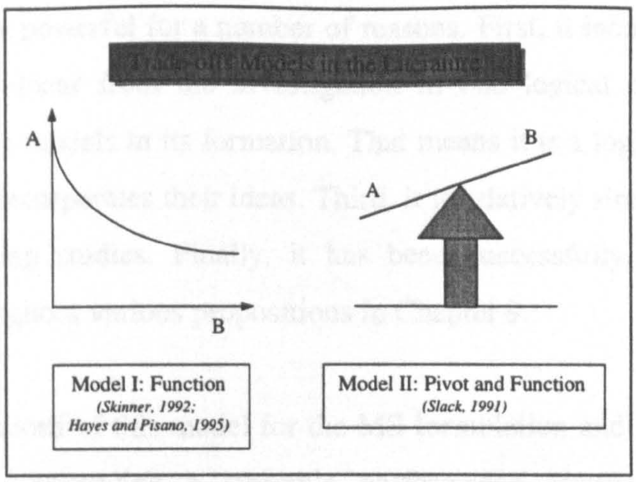

Figure 10-2: Models of manufacturing trade-offs from the OM literature

However, the research findings clearly suggest that those models can not explain most of the relationships that seemed to characterise trade-offs in the case companies. For example, they could not explain (a) how one may improve trade-offs; (b) what exactly constitutes the pivot in practice and (c) what is the role of resources and capabilities in trade-offs. The lack of development that seems to mark the literature on trade-offs has been noted in Chapter 9. It may be possible to speculate that this is partially due to the absence of models capable of incorporating better ideas of their elements and nature.

Consequently, the author believes that the development of an improved model of manufacturing trade-offs was one of the major requirements and is one of the major accomplishments of this research. This model has been suggested in Chapter 9, Proposition 3 and is presented again in Figure 10-3.

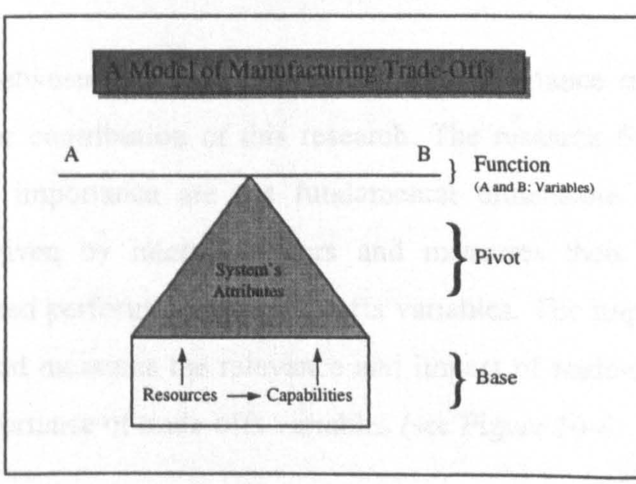

Figure 10-3: The research model of manufacturing trade-offs

This model may be powerful for a number of reasons. First, it incorporates a series of ideas that were evident from the investigation in one logical context. Second, it includes the former models in its formation. That means it is a logical evolution from those models and incorporates their ideas. Third, it is relatively simple and thus useful to ground following studies. Finally, it has been successfully tested against the research data throughout various propositions in Chapter 9.

The major implications of this model for the MS formulation and improvement seem as follows. First, improving a system's performance requires identifying and improving the key *resources and capabilities* of that system. Raising performance requirements or increasing control will have no positive effects if one does not understand what is behind the performance of a particular objective. Second, improvements can only be sustained in the long term if one focuses on the *relationships* between objectives rather than their individual performances. New resources and capabilities aiming to improve one objective's performance can only be successful if they have a positive or, at least, neutral impact in the remaining areas. Third, objectives, attributes, capabilities and resources are *distinct elements* and have distinct roles in the organisation, albeit they are closely related. Improving a system requires acknowledging these elements and defining measures that may have a positive effect in their network rather than in single elements.

The Distinction between Performance and Importance of Trade-offs

The distinction between the performance and the importance of trade-offs is also offered as a major contribution of this research. The research findings suggest that performance and importance are the fundamental dimensions of trade-offs. The performance is given by internal factors and measures their strength. It is the maximum combined performance of trade-offs variables. The importance is given by external factors and measures the relevance and impact of trade-offs in the MS. It is the combined importance of trade-offs variables (see Figure 10-4).

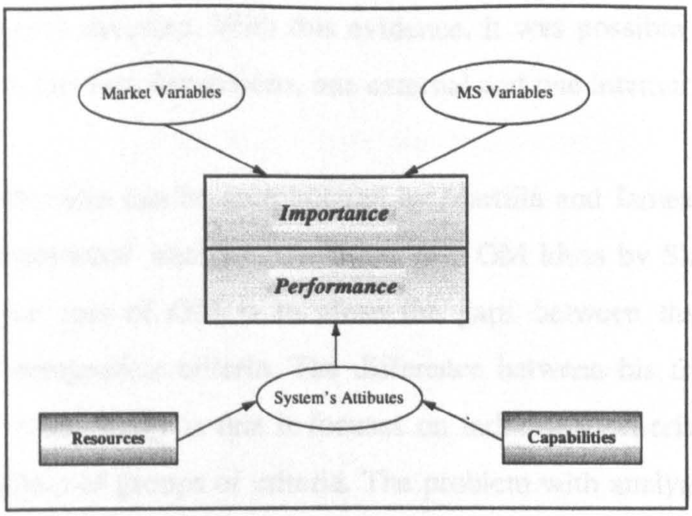

Figure 10-4: The importance versus performance of trade-offs

No other study on trade-offs has so far distinguished or fully articulated these dimensions. Some have suggested that trade-offs may have different levels of either importance or performance, but never considering the two dimensions as separate. Skinner (1992) referred to the varying *importance* of relationships in the context of operations. Hayes and Pisano (1994) suggested that Allegheny Ludlum had been *minimising* its trade-offs. New (1992) suggested that the *degree* of some trade-offs could change.

The initial research framework took these studies in consideration and thus did not anticipate this duality either. The researcher asked people in the companies to point out 'the importance' (as a combined dimension) of their trade-offs, imagining that this would be sufficient to qualify these phenomena. However, the analysis of these data clearly suggested that people qualified trade-offs along two different approaches. Some people assessed 'the relevance of trade-offs to MS'. For instance, M2 in Case A suggested that dependability versus variety was not important because of their MS: *"... by the way we do our business I don't think there is a big trade-off there."* However, other people would assess trade-offs from the point of view of operations. For example, M2 in Case C suggested that quality versus cost depended on work skills: *"This trade-off depends on work skills... asking quality to a skilled workforce should not cause any troubles in speed, but this is not the case with unskilled people."* This is also in the literature. Greis (1994) suggested that a CD trade-off depends on external factors such as variability of demand and internal factors such as system's capabilities and cost structure. With this evidence, it was possible to determine that trade-offs have in fact two dimensions, one external and one internal.

The validity of this idea can be corroborated by Martilla and James' (1977) study on 'Performance-Importance' analysis, translated into OM ideas by Slack (1994). Slack suggested that the role of OM is to close the gaps between the importance and performance of competitive criteria. The difference between his framework and the ideas proposed in this study is that it focuses on individual criteria while this study suggests the analysis of groups of criteria. The problem with analysing single criteria is that measures devised to close the gaps between one's importance and performance may have a negative effect on another criterion - without people's knowledge. The analysis of *trade-offs* (groups of criteria) could minimise (if not eliminate) this problem, as one would analyse the impact of those measures into different variables simultaneously. Focusing on individual criteria may lead to effects such as those discussed by Upton (1995) on the implementation of new technologies. He suggested that these may have side-effects if one does not consider a full set of variables at the time of their implementation.

The author thus believes that the distinction between the importance and the performance of trade-offs is relevant and is a valid contribution of this study. First, this idea is corroborated by this study's data. Second, it may improve the understanding of trade-offs in the context of operations systems. Third, it combines with existing frameworks in the literature, albeit they focus on individual criteria. Finally, it may improve the quality of decisions focused on closing the gaps between the importance and performance of groups of criteria rather than single dimensions.

The Taxonomy of Trade-offs Manufacturing Strategies

The taxonomy of trade-offs management strategies may be among the most original and important contributions of this study. Based entirely on the cases' evidence, this taxonomy suggests that trade-offs may be dealt with by a number of different options. These strategies are either Reactive or Proactive. Reactive strategies aim to adapt the system to the effects of trade-offs. These are divided into Priorities Setting, Reduction, Compensation and Equilibrium. Proactive strategies operate upon trade-offs, trying to change their function, pivot or base. These are divided into One-Side Improvement, Two-Sides Improvement and Relationships Improvement (see Chapter 9).

A taxonomy as such did not appear in the reviewed literature. Studies such as Hayes and Pisano (1994), Slack (1991) and Skinner (1992) discussed some approaches for changing trade-offs. However, these neither suggest that changing/adapting to trade-offs could follow alternative strategies nor (thus) propose a taxonomy as such.

This taxonomy has two major assets. From the theory point of view, it considers and integrates a wide range of manufacturing strategies within one framework. Assuming that manufacturing strategies aim essentially to tackle trade-offs, different trade-offs strategies may relate to different manufacturing strategies. For example, one may suggest a correspondence between Skinner's (1974) **Focused Factories** and *Reduction*, Porter's (1985) **Competitive Strategies** and *Priorities Setting*, Hammer's (1990) **Business Process Re-engineering** and *Two-Sides Improvement*, Pine's (1992) **Mass Customisation** and *Relationship Improvement* and Stalk's (1988) **Time-Based Strategy** and *One-Side Improvement*[1]. These relationships are first suggested here and should be further investigated, as will be discussed in the next section.

From a practical point of view, the major advantage of this taxonomy is that it provides a contingent approach in MS definition. As suggested in Chapter 9, different trade-offs strategies combine better with different variables such as (a) the level of resources and time available for dealing with a trade-off, (b) the firm's MS and competitive environment, (c) the range of performance and importance factors of the trade-off and (d) the nature of the trade-off. By comparing these variables with the

[1] Although Stalk (1988) suggested that time-based strategies have a positive impact in quality and cost as well, their measures essentially focus on speed reduction. Thus Stalk and Webber (1993) reported that time-based strategies alone may not guarantee benefits in other areas besides speed: improvements in other areas should rely on the **combination** of time-based with other strategies such as customer service. Von Braun (1990) also highlighted such failures. Thus time-based strategies are considered here as one-side improvement strategies.

objective and features of each strategy one may choose the one (or the combination of strategies) that may be most appropriate in the short and/or long terms.

For example, if a firm faced pressures to increase the competitive performance of one dimension (such as variety) and could afford to lose some ground in another (such as speed), it might employ a reactive strategy such as *setting variety a priority*. This could mean, in the shop-floor, reducing batch sizes without improving set-up methods. On the other hand, if was not possible to slip on speed or cost, they should at least focus on the *one-side improvement of variety*. Providing more variety at no expense of cost or speed would require more effort in improving resources (such as more flexible machines) and capabilities (such as set-ups) than with the previous idea.

Finally, it is possible to speculate that these strategies may be also related with Hayes and Wheelright's (1979a) Stages of Manufacturing Contribution or Sweeney's (1991) Taxonomy of Generic Manufacturing Strategies. A sequence such as through *Compensation/Equilibrium*, *Reduction*, *Priorities Setting* and (the series of) *Proactive Strategies* may conform with the idea of progressing through the increasing levels of manufacturing proactiveness suggested in those studies.

The Role of Manufacturing Flexibility and Variety in Trade-offs

This research brings two major contributions for the knowledge of flexibility. First, it distinguishes upon the role of flexibility and variety in trade-offs and OM. Second, it extends the knowledge about the relationships between trade-offs and flexibility types, resources and capabilities.

As suggested in Chapter 9, the understanding of the role of flexibility and variety in trade-offs improved in great extent along the investigation. This research starts by reviewing the diverse and sometimes contradictory ideas on the role of flexibility and variety in the literature (Chapters 2 and 3). It finishes with the striking finding that, at least in the context of trade-offs, variety rather than flexibility is in the level of MSDs.

This finding may have great implications for following research (discussed in the next section). First, it may help to solve the confusion about the role of flexibility and variety in the context of trade-offs. As pointed out in Chapter 9, while some studies discuss trade-offs between *flexibility* and other variables (Gerwin, 1993; New, 1992; De Meyer et al., 1989), other studies focus on trade-offs with *variety* (Upton, 1996; Mapes, 1996; Yeh and Chu, 1991; Kekre and Srinivasan, 1990; Nemetz and Fry, 1988). Second, it may also help to distinguish upon the ideas of flexibility and variety in a broader OM context - a problem defined by De Groote (1994) and Genus and Dickson (1995).

Notwithstanding its relatively less dramatic originality (or controversy), the second point may be as helpful for the research and development of flexibility as the first. The case companies provided a large number of examples of the impact of increasing flexibility types, resources and capabilities on trade-offs performance. These are summarised in Chapter 9, Figures 9-7 and 9-8. These examples show (1) that the impact of specific flexibility types, resources or capabilities is usually widespread in the organisation (rather than focused on specific variables) and (2) that flexibility is a key mover of trade-offs. The first idea has a large history in the literature, see for example Benjaafar, Talavage and Ramakrishnan (1995), Cox (1989) and Benjaafar (1994). The second idea also combines with existing studies such as Jaikumar (1986) and Tincknell and Radcliff (1996).

10.2 Topics for Further Research

The major aspects of this study that can be the subject of further research are as following. First, the fundamental research that should follow this study concerns the testing of the series of propositions defined in Chapter 9 for large samples. This testing should be conducted ideally as a survey targeting companies from different industries and with different sizes and competitive strategies.

Second, one should investigate in which extent it is possible to combine the different trade-offs management strategies proposed in the results. For instance, Case D suggested combining reactive strategies (priorities setting and reduction in that case) with a proactive strategy (two-sides improvement in that case) to deal with QS and CS. It is important to define in which circumstances one should stick to one strategy type rather than combining different types. It is also necessary to extend the knowledge about these strategies, to define the parameters of choice upon then (some parameters have been suggested but could be further discussed) and to compare the effects of these strategies with major paradigms from the literature. For example, one can suggest that Process Re-engineering means 'Both Sides Improvement' strategies as it focuses on a range of dimensions, while Mass Customisation Strategies mean 'Improving the Relationship' between variety and other dimensions.

Third, one should clarify what is the role of flexibility and variety in the context of MS. Most studies on MS content (reviewed in Chapter 1) suggest that flexibility is an MSD along with cost, quality, dependability and speed. However, it has been long suggested that the concept of flexibility is multi-dimensional and includes other MSDs in its formation. Hence it seems illogical to place flexibility in the same level of the others. Furthermore, the research suggests that trade-offs should be made between those MSDs and variety rather than flexibility (this was also the case with Mapes (1996), while Schroeder et al. (1996) reported problems with measuring flexibility as part of trade-offs). Finally, it is important noting that studies such as Yeh and Chu (1991) and Kekre and Srinivasan (1990) focused on the impact of variety rather than flexibility upon other MSDs.

Fourth, one should extend the findings concerning the distinction between operations objectives (or dimensions) and attributes to a larger context of MS. Authors such as Slack (1991) and Corbett and Van Wassenhowe (1993) suggested the existence of 'first and second order' or 'internal and external' objectives in operations. The researcher believes that these concepts compare with this study's distinction between objectives and attributes. Furthermore, the case studies provided a number of distinct attributes (flexibility, capacity, reliability, co-ordination) that should be integrated in a framework with those MSDs (including variety). Finally, it is possible to speculate that each of these attributes is a function of one specific MSD by all the remaining MSDs. For example, flexibility is a function of variety at certain levels of cost, quality, speed and dependability; reliability is a function of quality at certain levels of variety, cost, speed and dependability and so on. This hypothesis could be tested by using appropriate methods of quantitative analysis of operations performance.

Fifth, it would be interesting to investigate how Slack's (1994) Importance-Performance Matrix could handle the assessment of trade-offs. Obviously, since trade-offs seem to have a performance and an importance dimension, the use of this matrix for their assessment may be straightforward. However, this matrix could do more than identifying the performance and importance levels of trade-offs and thus their 'improvement zones'. It could show the *dynamics* of the impact of different trade-offs management strategies in trade-offs. This is to indicate how trade-offs would move within the matrix if specific strategies were taken. The combination of the matrix 'improvement zones' with the strategies types could be an effective method for trade-offs analysis and management.

10.3 Implications for Operations Managers and Researchers

The implications of this research for operations managers are as following. **First**, manufacturing trade-offs exist and thus must be recognised in operations management and strategy. Managers must identify the major system's trade-offs and assess their sources, nature and effects upon the organisation. **Second**, since trade-offs are dynamic, contingent and manageable, it is the role of OM to act upon those trade-offs whose importance is bigger than their performance. **Third**, this action should follow the choice of appropriate strategies to deal with trade-offs. This research provides a range of reactive strategies that may adapt the system to the effects of trade-offs. However, the researcher speculates that choosing proactive strategies to change the nature of trade-offs may have a superior and more lasting effect than the former type. **Fourth**, one must understand that trade-offs exist because competitive criteria are related. Furthermore, trade-offs themselves are inter-related. Therefore, OM must evaluate the impact that new or improving resources or capabilities may have upon a range of dimensions rather than upon single competitive criteria.

The implications for researchers are as following. **First**, this study shows that the research on manufacturing trade-offs must now progress from the descriptive stage to the explanatory and testing stages. It is necessary to develop and test propositions that may explain what is the meaning of trade-offs and why and how they happen within organisations. **Second**, researchers have to evaluate the impact of new operations strategies, technologies or methodologies upon a series of dimensions rather than upon single criteria. One must evaluate measures to improve the performance of, for example, quality or cost for their impact on the remaining MSDs as well. **Third**, the trade-offs framework developed within this research may help to understand and specially compare the increasing range of manufacturing strategies (such as Mass Customisation, Agile Manufacturing, TQM and Time-Based Strategies) aiming to tackle specific trade-offs. If one assesses these strategies within the same categories suggested in this research - sources, nature, effects and management actions - one may be able to trace valid comparisons and to assess their value across different contexts. Otherwise, the widely different frameworks provided by studies on each of these strategies seem to make this process very difficult.

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Appendix: Research Questionnaire

A. Manufacturing Objectives and Trade-Offs

1. What are the competitive importance and performance of these following manufacturing strategy objectives in your company today? How were then five years ago (or later: _______ (months/years))[1]?

Performance Scale

Extremely poor **1 2 3 4 5** **Extremely good**

Importance Scale

Extremely unimportant **1 2 3 4 5** **Extremely important**

Performance		Importance		Manufacturing Objectives
Before	After	Before	After	
				Cost
				Quality
				Flexibility
				Speed
				Dependability

2. Can you indicate which of these trade-offs between those objectives happen in your plant? How important are they?

Importance Scale

Extremely unimportant **1 2 3 4 5** **Extremely important**

If they do not exist, please mark 'N.E.'

Manufacturing Trade-offs	Importance
Quality and Cost	
Quality and Speed	
Quality and Dependability	
Quality and Flexibility	
Cost and Speed	
Cost and Dependability	
Cost and Flexibility	
Speed and Dependability	
Speed and Flexibility	
Dependability and Flexibility	

3. Concerning the most important trade-offs: Can you give an example of each trade-off as in practice? If management tried to eliminate it, how was it and how successful was this attempt?

____

[1] Which period of time is best related to the 'past' performance depends on the criteria of the interviewee. That also depends on the period of investment in new resources (question 4).

B. Resources and Flexibility Capabilities

4. Have some of these technologies or methodologies been implemented in this plant in the last five years? If so, could you please indicate when the implementation started and finished?

Start End

1. ______ to ______ Computer integrated manufacturing systems (CIMS);
2. ______ to ______ Computer aided design (CAD);
3. ______ to ______ Computer aided manufacturing (CAM);
4. ______ to ______ Computer aided process planning (CAPP);
5. ______ to ______ Flexible manufacturing systems (FMS);
6. ______ to ______ Numerical Control (NC);
7. ______ to ______ Automatic loading of parts and tools;
8. ______ to ______ Computerised Control Systems (CCS);
9. ______ to ______ Materials Handling and Storage Systems.
10. ______ to ______ Other Advanced Technologies (please specify)
11. ______ to ______ Design for manufacturability;
12. ______ to ______ Group Technology and Cellular Manufacturing;
13. ______ to ______ Set-up Time Reduction;
14. ______ to ______ Human resources policies (please, specify)
15. ______ to ______ System's management policies; (please, specify)
16. ______ to ______ Other Methodologies (please, specify)

Can you specify which manufacturing decision areas were most directly affected by the introduction of these technologies and methodologies?

Decision Area	Related Decisions	Tech/Meth (#)
Production Capacity	amount, timing, type	
Distribution	vendors, delivery times	
Facilities	size, localisation, specialisation	
Process Technology	scale, flexibility, integration	
Vertical Integration	direction, extent, balance	
Human Resources	selection, training, security	
New Products	start-up, modifications	
Organisation Structure	communication, management systems	
PPC Systems	organisation, scheduling, control	
Quality	definition, roles, responsibilities	
Research and Development	structure	
Suppliers	number, structure, relationship	

5. How good is the competitive performance of these flexibility capabilities now and how were they five years ago(or later: _______ (months/years))[2]? Please, use the following scale:

Extremely poor 1 2 3 4 5 **Extremely good**

Flexibility Capability	Bef ore	Aft er	Changed Because of	
			Tech Meth (#)	Other Sources
Product: (product design and modification)				
Mix: (production planning)				
Delivery: (scheduling)				
Production: (line set-ups)				
Volume: (inventory management, make vs. buy)				
Expansion: (production capacity management)				
Process: (use of alternative materials or production sequences)				
Programming: (production control vs. autonomy)				
Rerouting: (transportation of parts)				
Machine: (machine set-ups)				
Labour: (labour skills for responsiveness)				

6. Concerning the most important cases above: Can you explain how has a specific improvement affected the performance of a specific flexibility capability?

____

[2] This period of time should be the same as in question 1 and as in the other questions as well.

C. Production Capabilities

7. How good is the competitive performance of these capability measures now and how were they five years ago(or later: ______ (months/years))? Please, use the following scale:

Performance Scale

Extremely poor **1** **2** **3** **4** **5** **Extremely good**

Before	After	Production Capability Measures
		1. Overall Quality
		2. quality performance: cost with quality failures: % scrap, % rework
		3. quality conformance: cost with quality prevention / appraisal
		4. Overall Cost Productivity
		5. outputs / labour cost (variable + fixed)
		6. outputs / capital cost (fixed)
		7. outputs / materials + energy cost (variable)
		8. Overall Delivery Speed
		9. Operational Lead Time (machine time, workpart and tool handling)
		10. Set-up time
		11. Non-operational time (transportation, delays, inspection, queuing)
		12. Scheduling Lead Time
		13. Overall Dependability
		14. % of on-time deliveries
		15. average delay of deliveries
		16. % change in production schedules

8. Concerning the capability measures that have changed: Which technologies or methodologies (#) have affected their performance? Can you explain how it happened? Which activities most affect these measures?

____

D. Trade-offs, Capabilities and Resources

9. What was the impact of the *new resources in the performance of trade-offs? Was* this impact negative (that means the trade-off became more *strong), neutral (or 0, that* means the trade-off *did not* change) or positive (that means the trade-off became weaker or was eliminated)? Use the following scale:

			Impact			
very negative	**-2**	**-1**	**0**	**1**	**2**	**very positive**

tech/meth (#)	impact	example	trade-off
____________	______	______________	quality and cost
____________	______	______________	quality and speed
____________	______	______________	quality and dependability
____________	______	______________	quality and flexibility
____________	______	______________	cost and speed
____________	______	______________	cost and dependability
____________	______	______________	cost and flexibility
____________	______	______________	speed and dependability
____________	______	______________	speed and flexibility
____________	______	______________	dependability and flexibility

10. For each trade-off that has changed, can you indicate which of the following variables were more influential in this change?

A) An improvement in some flexibility capability, changing the nature or the environmental conditions of this trade-off. If so, please explain in which cases it happened and which improvements and flexibility capabilities were involved:

____

B) Another factor or capability. If so, please explain how and where it happened and which improvements and factors are involved:

____